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Assessment of Nonpoint Sources Areawide Waste Treatment Management Plan for the Greater Houston Area

Dannenbaum Engineering Corp, Houston, Tex

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ASSESSMENT
OF
NONPOINT SOURCES

JULY 1977

HOUSTON-GALVESTON AREA COUNCIL

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Dannenbaum Engineering Corp./Espey, Huston & Associates, Inc.

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Dannenbaum Engineering Corp.
P. O. Box 22292
Houston, Tx 77027

Espey, Huston & Associates, Inc.
3435 Branard, Suite 101
Houston, Tx 77027

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ASSESSMENT
OF
NONPOINT SOURCES

AREAWIDE WASTE TREATMENT MANAGEMENT PLAN
FOR THE
GREATER HOUSTON AREA
(SECTION 208, PL 92-500)

JULY 1977

PREPARED FOR THE HOUSTON-GALVESTON AREA COUNCIL
BY
DANNENBAUM ENGINEERING CORPORATION/
ESPEY, HUSTON AND ASSOCIATES, INC.

FOREWORD

This document has been prepared by Dannenbaum Engineering Corporation and Espey, Huston and Associates, Inc. as part of a Nonpoint Source Analysis contract with the Houston-Galveston Area Council (H-GAC). The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and accompanying regulation require an examination of nonpoint sources of water pollution. The H-GAC has been designated as one of the planning agencies to develop an areawide waste treatment management plan under Section 208 of PL 92-500.

This report is an assessment of the nonpoint sources of water pollution within the Greater Houston 208 Planning Area. This report includes assessments of water pollution resulting from urban runoff, septic tank seepages, agricultural runoff, construction site runoff, dredging, and benthal oxygen demand. This information will, in turn, be used to plan control strategies for these nonpoint sources. This volume contains Chapters I through V of the Nonpoint Source Analysis contract output. Chapter VI is the Nonpoint Source Sampling Design Report; Chapters VII through IX are the Nonpoint Source Control Strategies, Costs, and Impacts; and Chapter X is an Executive Summary of the nonpoint source assessment and control strategies.

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CHAPTER I - PRELIMINARY ASSESSMENT OF URBAN RUNOFF IMPACT

PRELIMINARY ASSESSMENT OF URBAN RUNOFF IMPACT

Scope of Work

The general purposes of this assessment were to: 1) Provide a general narrative as to the characteristics and impacts of urban runoff and 2) to estimate the existing and projected magnitude and points of impact of stormwater runoff in the Greater Houston 208 area. The methodology utilized in this effort involved existing data and no field sampling was accomplished. Where possible, the information obtained was oriented toward improving the accuracy of applicable water quality prediction models.

In the conduct of the work the Water Data Base Information developed by the City of Houston, the USGS water quality data, and the data compiled by Rice University was analyzed to develop loading rates for various pollutants. Where possible, the analysis of the data to estimate loading rates included analysis of physical and hydrologic parameters such as land use, drainage area, ground slope, rainfall data, inches of runoff, time from storm start, peak discharge, percent of impervious area in the watershed, and other nonpoint contributions.

The pollutant contribution by each signifcant tributary subbasin into the streams and bays was evaluated using the Stormwater Management Model (SWMM) to produce hydrographs, pollutographs, and other output data described in this scope of work. For the subbasins that were not analyzed by the SWMM model, the U.S. Army Corps of Engineers HEC-1 program and updated variables were to be used to predict the output hydrographs and pollutographs. The regression analyses developed included all data collected in the Houston area by the USGS, Rice University, and the TWQB. Additionally, data from other urban areas where collection and analysis have been performed was evaluated for use in the Houston area.

Using the SWMM and the existing Houston area data and literature values, loading rates for several degrees of land use and physical conditions were developed for selected subbasins so that future condition loadings could be estimated for the entire study area. The SWMM model was exercised for three storm conditions for the present time period and one storm for future conditions in 5, 10, and 20 year time periods. The storm condition for future time periods is based upon selection by H-GAC staff and advisors. Literature values and default values currently utilized in the SWMM were used as evaluative tools to analyze the derived loading rates for the Houston area. The loadings for all subbasins in the study area were then predicted using the loading rates developed for the Houston area. The Methodology for the determination of urban runoff impacts for use by the water quality management agencies was made available to H-GAC.

As delineated in the consultant's contract, outputs from this task included:

1) A map showing the study area with drainage sub-basins delineated (covering the entire area) and highlighting the points of discharge to major streams.

2) For each significant subbasin, tables were submitted presenting peak flow, total runoff, first flush concentrations, net DO contribution and total loading values for BOD_5, total suspended solids, nutrients, and coliforms for the design storms. This data was developed for present conditions and the worst case condition for 5-, 10-, and 20-year increments.

3) For the stream segments listed below, hydrographs (CFS) and pollutographs for BOD_5 (mg/l), TSS (mg/l) and fecal coliforms (MPN/minute) were developed at each source (storm sewer or tributary) entering the main segments for the three design storms under present conditions and a selected storm event for future conditions:

   Spring Creek (Segment 1008)
   Cypress Creek (Segment 1009)
   Lower San Jacinto River (Segment 1001)
   Houston Ship Channel (Segment 1006, 1007)
   Clear Creek (Segment 1102)

4) A discussion of possible limitations of the output due to methodology limitations and the amount or quality of available data was included.

5) A general narrative explaining in qualitative terms, the physical, chemical, and biological effect of stormwater runoff upon segments within the study was also included. This effect is explained in terms of the impact upon water quality, public health, and commercial sport and shell fishing.

Summary and Conclusions

In the accomplishment of the water quality assessment for this element of the H-GAC 208 Waste Treatment Management Program, an attempt was made to develop a quantification of the impact of non-point pollution sources on water quality. Unlike many areas of the country which are currently conducting similar 208 Program efforts, this area was fortunate to have an existing data base in the sampling work accomplished at the Woodlakes, in the data compiled by Rice University, and other agencies in the study area. As fortunate as that data availability was, it was found that the data was not available in sufficient number to provide adequate satistical reliability. The scope of investigation was therefore broadened to include the published nonpoint source literature for several areas of the country where measurements have been made.

An analysis of 108 runoff events, representing nine watersheds from various cities nationwide, has indicated a strong correlation between the log of the cumulative runoff volume and the log of the cumulative pollutant load. This association was used to develop, by regression analysis, a stormwater quantity-quality model of the general form,

$$y = ax^b$$

where y is the pollutant load in pounds per acre, x is the runoff in inches, and a and b are coefficients developed during the analysis.

Although adequate correlations between pollutant concentration and volume of discharge were found for most of the parameters investigated, the correlation coefficients for nutrient data proved unsatisfactory. Because of the inadequacies of the data considerable judgement was often required to accomplish the calculations and projections herein. Unfortunately, neither funding nor time were available to speculate as to the reason for the poor correlation coefficients of the nutrient data. Because of the expense of developing additional data, it is recommended that the U.S.E.P.A. be the source agency for such investigation on a national scale rather than the effort be borne by the H-GAC Continuing Planning Program.

Analysis to determine associations between the quantity-quality relationships and land use characteristics found that the land use characteristic which yielded the highest degree of association was percent of impervious land cover. While the degree of correlation for this land use factor was the strongest, the analysis indicated that other factors such as vegetative cover, soil type, and other environmental factors may play an important role.

During the course of this investigation, it was found that where as the total pollutant load is a function of the total runoff generated during a runoff event, it is not indicative of the peak concentrations produced during that event. In general, as the duration of a given runoff event increases, the peak pollutant concentration will decrease.

enterococci indicate that urban runoff can degrade the quality of a receiving stream as a pollutant comparable to by-passed flow from combined sewers, or raw sanitary sewage, in certain cases. (4)

The earliest reported study of the pollutional level of urban storwmater runoff in the United States was made in 1950 by Palmer. (5, 2) Palmer sampled urban stormwater runoff from land surfaces at street catch basins in downtown Detroit. Although the data were considered to be limited by Palmer, he felt that the results supported the contention "that stormwater run-off from highly urbanized and highly populated areas is heavily polluted and would be but slightly less objectionable in the receiving waters than the run-off flow from combined sewers." (6) Thus, as was the case of sewage treatment, concern for the possible pollutional effects of stormwaters apparently originated in the city with regard to the effects of urbanization on stormwater pollution. Later investigators of the subject concentrated not only on separate and combined stormwater and sewerage systems in urban areas, but on semiurban and rual areas where they attempted to estimate the pollution emanating from these sources. (7)

The dominant consideration in most early studies of urban runoff was the presence of large concentrations of coliform bacteria which suggest the presence of potential pathogenic organisms. Another matter of concern equally important to public health is the presence of toxic or other chemical substances entering public water supplies. As far as stream or lake pollution is concerned, the amounts of suspended solids (both volatile and fixed), total solids, dissolved oxygen and biochemical oxygen demand are also important. (7)

Pollutants in stormwater originate either in the atmosphere or on the land. Airborne contaminants, the atmospheric source, exist in the form of particulates and gases. In the Houston area a substantial amount of air pollution is of natural origin, including weathering, dust storms, tree emissions, and forest fires.

In most areas, however, the significant harmful air pollution is man-made, resulting from refining, manufacturing, incineration, construction, and combustion of fuels for electrical power generation, heating, and automotive power. The five principal categories of air pollutants are oxides of sulfur and nitrogen, hydrocarbons, carbon monoxide, and particulate matter. If the scavenging (wash out) of these pollutants by precipitation is assumed proportional to the rate of precipitation it may represent a significant contributor of nonpoint loads especially in highly urbanized and idustrial areas. Although suspended particulates comprise only about one percent by weight when combined with the major gaseous pollutants, the total annual dustfall in urban areas can range from 500 to 900 tons per square mile (1562.5 to 2812.5 lbs./ac./yr.). (8) While little

In the development of correlation coefficients between water quality parameters and runoff volume, it was also found that the coefficients of determination (the square of the correlation coefficient) were higher for those data correlations reduced for log-log regression analysis than those for linear regression analysis. As with the nutrient correlation observations, neither sufficient time nor funding was available to allow speculation as to the reasons underlying the observation. Additional discussion of the regression analyses is contained in the methodology text of this report.

General Characteristics of Urban Runoff

Until recently, concern with regard to pollution of rivers and streams has focused only on control of municipal and industrial sources, or the "point" sources of pollution. Stormwater has been ignored as a source of pollution, probably due to its direct association with rainwater, which even today is mistakenly assumed to be "pure" by the general public. (1)

Although the term "pollution" is generally associated with man and his activities affecting the environment, it should be recognized that even without human activity, streams are subject to natural pollution. (2) These natural sources take the form of soil erosion, decomposition of vegetation and animals, animal wastes, and solution of minerals.

An editorial on a Council on Environmental Quality (CEQ) study (3) revealed that in most cases higher flows resulting from urban runoff did not "dilute" point source pollution, but caused lower quality than normal flows. The water quality downstream of the urban areas studied was found to be controlled by the point sources only 20 percent of the time. The measurements are available for the Houston area to localize this data. Increased interest in other potential pollution sources has evolved as water pollution concerns have expanded to include problems associated with nutrients, sediment, persistent chemicals, and toxic materials. These sources of pollution have been grouped into a general category of "non-point" sources, which are dependent, in more cases, upon rainfall-runoff. (1)

Urban runoff is the surface runoff of stormwater within an urban area. Stormwater falling through the atmosphere, flowing across yards and paved surfaces, off the roofs of homes and buildings and through parks, fields and ditches picks up and carries to receiving streams numerous pollutants. Research on the characteristics of urban runoff pollution indicates the seriousness of the problem has been highly underrated. Appreciable contaminants measured as suspended solids, BOD, COD, nitrogen forms, phosphates, hydrocarbons, metals, total bacterial counts, coliform and fecal enterococci indicate that urban runoff can degrade the quality of a receiving stream as a pollutant comparable to by-passed flow from combined sewers, or raw sanitary sewage, in certain cases. (4)

The earliest reported study of the pollutional level of urban stormwater runoff in the United States was made in 1950 by Palmer. (5, 2) Palmer sampled urban stormwater runoff from land surfaces at street catch basins in downtown Detroit. Although the data were considered to be limited by Palmer, he felt that the results supported the contention "that stormwater runoff from highly urbanized and highly populated areas is heavily polluted and would be but slightly less objectionable in the receiving waters than the runoff flow from combined sewers". (6) Thus, as was the case of sewage treatment, concern for the possible pollutional effects of stormwaters apparently originated in the city with regard to the effects of urbanization on stormwater pollution. Later investigators of the subject concentrated not only on separate and combined stormwater and sewage systems in urban areas, but on semiurban and rural areas where they attempted to estimate the pollution emanating from these sources. (7)

The dominant consideration in most early studies of urban runoff was the presence of large concentrations of coliform bacteria which suggest the presence of potential pathogenic organisms. Another matter of concern equally important to public health is the presence of toxic or other chemical substances entering public water supplies. As far as stream or lake pollution is concerned, the amounts of suspended solids (both volatile and fixed), total solids, dissolved oxygen and biochemical oxygen demand are also important. (7)

Pollutants in stormwater originate either in the atmosphere or on the land. Airborne contaminants, the atmospheric source, exist in the form of particulates and gases. In the Houston Area a substantial amount of air pollution is of natural origin, including weathering, dust storms, tree emissions, and forest fires.

In most areas, however, the significant harmful air pollution is man-made, resulting from refining, manufacturing, incineration, construction, and combustion of fuels for electrical power generation, heating, and automotive power. The five principal categories of air pollutants are oxides of sulfur and nitrogen, hydrocarbons, carbon monoxide, and particulate matter. If the scavenging (wash out) of these pollutants by precipitation is assumed proportional to the rate of precipitation it may represent a significant contributor of nonpoint loads especially in highly urbanized and industrial areas. Although suspended particulates comprise only about one percent by weight when combined with the major gaseous pollutants, the total annual dustfall in urban areas can range from 500 to 900 tons per square mile (1562.5 to 2812.5 lbs/ac/yr). (8)

While little dustfall data has been accumulated for the Houston area, these values can probably be assumed to be typical and therefore represent a major source of urban nonpoint pollutants.

The second predominant source of the pollutants in stormwater consists of the particulate matter on the land surface available for "flush". The amount of dust, dirt, and other contaminants on streets and other land surfaces is affected by the frequency of precipitation and the land use activity within the area. Sartor et al. (9) in their study of twelve United States cities sampled for a variety of pollutants found on street surfaces. The heavy metals investigated in the run-off from those study areas were found to have concentrations from one to two orders of magnitude greater than that found in domestic wastewater.

For those contaminants which are available for flush on street surfaces, it has been found (9) that approximately 78 percent of the contaminants are located within six inches of the curb and 95 percent are within 45 inches of the curb. Much of this curb side pollution comes from various types of combustion particulate emissions. As these emissions vary with the concentrations of motor vehicles and the combustion of other fuels and materials, land use and traffic pattern have a substantial effect on the available pollution load.

The urban runoff pollutants which have been generally classified above as to their origin at the time of solution or suspension in stormwater can be further associated with potential sources as shown in Table I-1. As can be seen from Table I-1, any one of the measurable water quality parameters in the second column could come from more than one potential source in the third column. The table therefore exemplifies one of the greatest difficulties of developing causal relationships between land use or activity and water quality impact: oxygen demanding substances, for example, do not carry with them an identification as to their source.

While the impacts of an urbanized area may be measured to great detail at a downstream point, the remaining 95 percent of the problem solution remains to identify where those pollutants or stream loads originated. The methodology for such source identification has customarily been to concentrate the measurement of pollutant load on specific land uses and attempt to develop "generation factors" unique to single land uses or activities and then apply those loading "factors" to all the similar activities within a study area. In that manner, the downstream pollutant load could better be assigned to the contributing sources. As might be expected, this calibration or development of unique generating factors for an area is an expensive undertaking which requires substantial amounts of personnel and materials to do the sampling and analysis. It is because of

TABLE I-1

POTENTIAL POLLUTION SOURCES (2)

Pollution Category	Measurable Parameter	Potential Sources
Bacterial	Coliform (Total, Fecal, Fecal streptococcus)	Warmblooded animals (Humans, Land mammals, birds) Soil or vegetation
Organic	BOD COD TOC	Organic matter (Leaves, Grass clippings, humans, and other mammals) Oil and grease
Nutrients	Nitrogen Phosphorus	Fertilizers Leaching from minerals Decomposition of organic matter
Solids	Suspended solids (Clay, Silica, and Orgnaic matter)	Erosion of cleared land Dust and dirt from streets Unimproved drainage channels
	Dissolved solids (Carbonates, Chlorides, Sulfates, Phosphates, Nitrates of calcium, and Organic matter)	Erosion of cleared land Leaching from minerals Soluble dust and dirt from streets

economics and time that relatively few of such intensive quantification projects have been funded, usually by Federal grant. Other 208 study areas such as the H-GAC Designated Area, in the absence of specific funding to accomplish detailed calibration studies, must rely on the data available from published literature on urban runoff quality and/or use the best available information from existing water quality monitoring programs.

In the following section of this report, as attempt was made to summarize the water quality impacts which have been associated with urban runoff in the Houston designated areas. Following that general summary of the available data from the literature, the methodology utilized in the development of urban stormwater impacts for the H-GAC 208 Area will be described.

Impacts of Urban Runoff

The purpose of this section is to dicuss, in qualitative terms, what effect urban runoff pollution has on water quality, public health, and commercial sport and shell fishing in the Greater Houston 208 Area. Two general types of runoff pollution are considered in the discussion, biodegradable and non-biodegradable. (10) Biodebradable pollutants are usually defined as those which can be readily decomposed by natural environmental processes. Pollutants in this category include organics, nutrients, and some forms of solids. When the input of these pollutants exceeds the natural decomposition or dispersal process, septicity of streams and the elimination of normal aquatic life can occur. (11, 10)

Non-biodegradable pollutants, such as heavy metals, certain pesticides, and inert or fixed solids, are those which cannot be readily decomposed by natural environmental processes. Even if these pollutants are not discharged in toxic concentrations, some may tend to be biologically magnified. That is, aquatic organisms will tend to build up increasingly larger concentrations in their metobolism be comsumption. (11) At some point these concentrations may reach toxic levels.

A major component of both biodegradable and non-biodegradable nonpoint source pollution is sediment which ends up as suspended solids or moving bed load materials. Sediment reduces water recovery streams, curl quality and often degrades deposition areas such as reservoirs, through increased benthal oxygen demand. Sediment occupies space needed for water storage in reservoirs, lakes, and ponds, restricts streams and drainage ways, alters aquatic life and reduces the recreational and consumptive use value of water through increased turbidity may increase flood potential. More importantly, sediment carries with it other water pollutants such as nitrogen, phosphorus, organic matter, pesticides, pathogenic organisms, and heavy metals.

Nutrients, primarily nitrogen and phosphorus, are necessary for the growth of aquatic plant life and therefore ultimately the aquatic animal life that feeds on it. However, when the receiving water receives an over-enrichment of these nutrients, such as from stormwater runoff, cultural eutrophication, or accelerated aging, can take place. This situation can be easily recognized by the appearance of numerous algae blooms, foul odors, and ultimately a reduction in the aquatic plant and animal population. (11)

The effect of runoff on health is much more difficult to define. The World Health Organization (12, 13) has defined health as, "A state of complete physical, mental, and social well being and not merely the absence of disease". From this general definition, therefore, impacts on public health from runoff might be categorized as follows:

1) Illness or disease resulting from bacterial, viral, or chemical contamination, including increased coliform loadings in Houston streams.

2) Nuisance odors and visual deterioration of areas adjacent to polluted water.

3) Decreased recreational opportunity resulting from polluted water.

Disease resulting from water pollution can result either from direct consumption of that water or more commonly from eating aquatic animals, such as shellfish, coming from these waters. Aquatic organisms will consume both organic and inorganic pollutants either directly or by ingesting other organisms which have themselves become contaminated. Over a period of time potentially toxic concentrations of pollutants can build up in the organisms. If these contaminated organisms are ultimately consumed by man, pathogenic bacteria or virus and other toxicants may cause injury to health.

The impact on commercial and sport fishing will be two fold. First, pollution will result in a reduction in number of aquatic life, such as fish, available for harvest. The resulting impact will be felt on both the public, in terms of high prices, and the industry, in terms of lower yield. Second, as the threat of contamination to the remaining fish and shellfish becomes greater, their use as a food source by the public may become unacceptable.

Urban runoff pollution has been compared (4) to pollution from combined sewer overflows. Table I-2 compares representative values of BOD, suspended solids (SS), total coliform, total nitrogen and total phosphorus for the following wastewater: raw domestic municipal and treated municipal wastewaters combined sewage, and surface runoff. Laeger and Smith (14) calculated annual discharges to a receiving water from a hypothetical city of 100,000. These calculations were carried out for the city being served by a combined sewage system and a separate system. The resulting flows, BOD, and SS loadings are listed in Table I-3. The chemical and biochemical characteristics of urban runoff recorded in a number of studies, including those referenced in this paper, as compiled by Loehr (15) are presented in Table I-4.

The City of Tulsa, Oklahoma (2), served by a separate storm runoff collection and discharge system, documents the following percentage of the total pollutional load (stormwater runoff plus municipal effluents) to it receiving streams by urban storm runoff:

Pollution Parameter	Percentage
BOD	20
COD	30
Suspended Solids (SS)	85
Organic Nitrogen (N)	30
Soluble Orthophosphates (P)	4

These percentages are expected to corresponding well with values in the Houston area because both have the same effluent criteria for municipal sewage treatment plants (10 mg/l BOD and 15 mg/l SS).

Table I-5 documents actual discharge loads from the Tulsa storm sewer system and municipal domestic wastewater treatment plants. The percent contribution of the storm runoff pollution to the total pollutional load is also given.

Tables I-2, I-3, and I-5 point to the fact that the amount of suspended solids loading on streams from stormwater runoff is substantial compared to that of domestic wastewater treatment plant effluents. In addition to the solids loading, stormwater runoff carries 20 to 30 percent of the BOD and nitrate loadings to receiving streams.

Due to their direct public health aspects, the bacteriological characteristics of stormwater pollution are of equal concern with respect to pollution of streams and lakes as physical, chemical, and biochemical characteristics. Total and fecal coliforms have been traditionally used to indicate possible pathogenic contamination. (16) Geldreich, et al. (17) performed an extensive bacterial analysis of stormwater in Coshocton, Ohio. Stormwater was examined from city

TABLE I-2

QUALITY COMPARISONS OF TYPICAL WASTEWATERS (4)*

	BOD_5 (mg/1)	SS (mg/1)	Total coliforms (MPN/100 ml)	Total nitrogen (mg/1 as N)	Total phosphorus (mg/1 as P)
Untreated municipal	200	200	5×10^7	40	10
Treated municipal					
Primary effluent	135	80	2×10^7	35	8
Secondary effluent	25	15	1×10^3	30	5
Combined sewage	115	410	5×10^6	11	4
Surface runoff	30	630	4×10^5	3	1

*Average of Samples Taken

TABLE I-3

COMPUTED ANNUAL DISCHARGES TO RECEIVING WATER FOR A HYPOTHETICAL CITY OF 100,000 (14)

Item Description	Flow (mil gal)	BOD_5 (1,000 lb/yr)	SS (1,000 lb/yr)
Case 1 - Sewered on combined plan			
Municipal effluent			
Dry weather	3,600	750	450
Intercepted wet weather	300	60	40
Combined sewer overflows	2,100	2,000	7,180
Total	6,000	2,810	7,670
Case 2 - Sewered on separate plan			
Municipal effluent			
Dry weather	3,600	750	450
Infiltrated municipal overflows	300	290	1,020
Storm sewer discharges	2,100	530	11,030
Total	6,000	1,570	12,500

Assumptions: Population density - 20 persons/acre
Degree of treatment of municipal flows - secondary (100 gcd)
Average annual rainfall - 33 inches during 760 hours
Runoff coefficient - 0.5
Flow-weighted mean concentrations
Effective interceptor/treatment capacity = 2.0 x dry-weather flow

TABLE I-4

URBAN LAND DRAINAGE AND STORMWATER OVERFLOW CHARACTERISTICS* (15)

Item and Location	Total Solids	Suspended Solids	COD	BOD	TKN	NO_3-N	Total N	Soluble P	Total P	Cl	Reference (to Loehr)
Concentration (mg/l)											
Cincinnati, Ohio	—	227 (5-1,200)	111 (20-610)	17 (1-173)	—	—	3.1 (0.3-75)	—	1.1 (0-7.3)	—	1 (1962-64)
Seattle, Wash.	—	—	—	—	2.0	0.53	—	0.08	0.21	—	22
Tulsa, Okla.	545 (200-2,240)	367 (84-2,050)	85 (42-138)	12 (8-18)	0.9† (0.4-1.6)	—	—	0.38 (0.18-1.2)	—	12 (2-46)	48
East Bay Sanitary District, Calif.	1,400	1,400	—	87 (3-7,700)	—	—	—	—	—	5,100	49
Los Angeles County, Calif.	2,910	—	—	160	—	—	—	—	—	200	49
Washington, D. C.	—	2,100 (26-36,200)	—	126 (6-625)	—	—	—	—	—	42 (11-160)	49
Detroit, Mich.	(310-910)	(102-210)	—	(96-234)	—	—	—	—	—	—	49
Madison, Wis.	—	(20-340)	—	—	—	(0.4-2.0)	—	(0.2-1.8)	(0.5-4.0)	—	50
Durham, N. C.	2,730 (274-13,600)	—	179 (40-600)	16 (2-232)	—	—	—	—	0.6 (0.16-2.60)	13 (3-390)	51 (1968-70)
Russia											
Rainwater runoff	—	(450-5,000)	—	(12-145)	—	—	—	—	—	(6-32)	52
Street washing water	—	(31-14,500)	—	(6-220)	—	—	—	—	—	(11-17)	52
Melting snow	—	(670-4,950)	—	(5-105)	—	—	—	—	—	(6-58)	52
Moscow	(1,000-3,500)	—	—	(186-285)	—	—	—	—	—	—	49
Leningrad	14,500	—	—	36	—	—	—	—	—	—	49
Stockholm	(30-8,000)	—	—	(17-80)	—	—	—	—	—	—	49
Area yield rate (kg/yr/ha)											
Cincinnati											
Stormwater runoff	—	640	310	47	—	—	0.8	—	1.1	—	9
Combined sewer overflow	—	280	—	—	—	—	6.8	—	5.6	—	9
Tulsa, Okla.	1,400 (650-5,700)	—	220 (67-530)	30 (13-54)	2.1 (1.2-4.0)	—	—	1.0 (0.4-3.0)	—	—	48
Detroit, Mich. (kg/ha)	—	220	—	100	8.8	0.2	—	2.1	4.0	—	53 (June-Aug. 1965)
Ann Arbor, Mich. (kg/ha)	—	1,230	—	35	1.2	0.9	—	0.3	1.0	—	53
Rock Creek (Potomac), Washington, D. C.	—	—	—	—	2.9	12‡	—	—	1.6	—	23 (60% urban, 30% farm)
Durham, N. C. (1968-70)	14,200	—	93	75	—	—	—	—	3.0	—	51
Stockholm, Sweden											
Highway runoff	2,040	1,185	—	100	—	—	5.1	—	0.2	—	54
Terrace house runoff	470	173	—	14	—	—	1.4	—	0.04	—	54
Residential block runoff	930	620	—	43	—	—	3.6	—	0.16	—	54

*Average characteristics, range of values shown in parentheses.

†Organic N.

‡NO_2 + NO_3-N.

TABLE I-5

ESTIMATED ANNUAL LOAD OF POLLUTANTS ENTERING THE AREA RECEIVING STREAMS TULSA, OKLAHOMA (2)

Pollutant	Average annual storm sewer discharge pollution load (lb)	Contribution of storm sewer discharges to total load (percent)	1968 Average annual load from treatment plant effluents* (lb)
BOD_5	1,630,000	20	7,060,000
COD	11,200,000	31	24,400,000
SS	39,000,000	85	6,710,000
Organic (Kjeldahl) nitrogen	130,000	31	278,000
Soluble orthophosphate	171,000	4	4,180,000

* One primary (21 mgd) and three secondary (19 mgd, total) plants.

streets, a suburban business district storm drain, a wooded hillside adjacent to a city park, and cultivated farm fields.

In reviewing stormwater runoff characteristics, there is no doubt as to its potential significance as a source of water pollution to lakes and streams. The quality of runoff varies from relatively "pure" , similar to uncontaminated precipitation, to a septic or toxic condition capable of destroying fish and wildlife or having detrimental effects upon humans when ingested through contamination of domestic water supplies.

Pollutant Loading Function Development

Introduction

Current stormwater modeling strategy, as normally formulated, involves 1) assembling a data base, 2) calibration of the model, 3) simulation of existing and future conditions, 4) the analysis of these forecasts, and 5) use of the forecasts in planning decisions. (25) The data base, therefore, provides the foundation on which both modeling and subsequent decision analysis will be carried out. Because of its importance in this overall strategy, it has been estimated that the distribution of cost and effort between data collection and modeling (including analysis) should be about 50 percent for each. Unfortunately, in the past, this balance of effort was rarely attained. The purpose of this section, therefore, is to describe 1) the development of such a data base, as derived from the existing literature, and 2) methodology for the use of such data in the modeling phase of this task.

At present, the best simulation model (26, 27) for predicting stormwater runoff quality is one which utilizes the following equation:

$$P_{(t+\Delta t)} = P_{(t)}e^{-KR\Delta t}$$

Where: P is the total pounds of pollutants on the surface of the watershed at the beginning of the storm

t is time measured from the start of storm

Δt is the time interval over which the integration is occurring

K is a decay constant which is normally assumed to be approximately 4.6

R is the actual runoff rate, measured in inches per hour

The equation, which was originally developed by Metcalf and Eddy, Inc. as part of the EPA Storm Water Management Model (SWMM) has shown fairly good results where $P_{(o)}$ is known. (26) There are generally two methods for evaluation $P_{(o)}$. The first is to use a literature value, most notably from an APWA study of the Chicago area. (8) The values from that work are based on street surface samples taken from various land use types in and around the south side of Chicago. Since the measurements were taken only of what was on street surfaces, the values neglect pollutants which accummulate on non-street areas. In general, experience has shown that the Chicago values rarely give accurate results in SWMM modeling. They are, however, still widely used when estimating stormwater runoff quality in areas where little or no recorded quality data exists.

The second method for estimating $P_{(o)}$ is by calibration against recorded stormwater runoff quality data. This method involves estimating $P_{(o)}$ and generating a single or set of pollutographs for an actual rainfall - runoff event(s). The computed pollutograph is then compared against a recorded pollutograph. If the two vary significantly, $P_{(o)}$ is re-estimated and a new pollutograph estimated. The estimation process is continued until a satisfactory match has been achieved. Unfortunately the results are only applicable for the watershed for which the calibrations were carried out.

In short, therefore, quality loading rates used as input into the SWMM are based on limited and perhaps inappropriate data or on model manipulation - calibration which is rarely reproducible.

The purpose of this section of the report is to describe the development of a data base from which predictive stormwater quantity-quality equations could be derived from statistical analysis. The equations developed were subsequently used to determine pollutant loading rates for subcatchments in the H-GAC 208 Planning Area.

Data Sources

Nine watersheds were chosen for analysis from six different studies. The data for the watersheds include a total of 109 runoff events. It was found during the literature review that considerably more stormwater runoff quantity-quality data were available than had been expected. Unfortunately, a considerable portion of these data were found to be unusable because watershed characteristics were inadequately described or because sampling techniques, such as sampling intervals, were of poor quality. The data presented here, therefore, represent the best available data at this time. Table I-6 presents a description of those watersheds used in this analysis.

TABLE I-6

DESCRIPTIONS OF WATERSHEDS USED FOR ANALYSIS

	Watershed	Area (ac.)	Percent Impervious	Number of Events	Description of Land Use
1.	39th and Holdrege Lincoln, Neb. (28)	79.	24	18	Older family dwellings and a limited number of multi family dwelling. Assume 90% S.F.R. and 10% M.F.R.
2.	63rd and Holdrege Lincoln, Neb. (28)	85.	22.5*	14	10 thru 15 year old single family residential. Assume 100% S.R.F.
3.	78th and A Lincoln, Neb. (28)	375.	15.0*	10	Area under development for single family residential and consisting of homes less than 10 years old, homes under construction, undeveloped lots and farm land.
4.	Third Fork Durham, N.C. (21)	1069.	29.0	35	Consists of 59% residential development; 19% commercial and industrial; 12% public and institutional lands; and 10% vacant.
5.	P-10 (29) Woodlands, Tex.	16050.3	1.0*	4	Primarily undeveloped woodlands.
6.	P-30 (29) Woodlands, Tex.	21006.7	10.0*	5	Area under development for single and multi-family residential with related commercial developments.
7.	Hunting Bayou Houston, Tex. (29)	1976.	23.0	4	Residential and commercial with some industrial developments.
8.	Texas Tech Lubbock, Tex. (30)	223.	30.0	11	Essentially residential development with no industrail development, although one commercial shipping center with accompanying parking lot and two schools are present.

TABLE I-6 (Contd.)

DESCRIPTIONS OF WATERSHEDS USED FOR ANALYSIS

Watershed	Area (ac.)	Percent Impervious	Number of Events	Description of Land Use
9. Selby Street San Francisco, Ca.(31)	3400.	22.0	7	Consists of 77% residential; 2% commercial, 6% industiral; and 15% vacant land.
		TOTAL	108	

* Estimated based on land-use.

These data were then used as the data base to evaluate the affects of different surface characteristics, such as land use, on the quality of stormwater runoff.

Methodology

The analysis of the data base is specifically directed towards the development of a predictive model which, with given parameters of runoff quantity and watershed characteristics, will predict runoff quality. The analysis was carried out in three steps which can be summarized as:

Step (1) The preliminary screening phase made liberal use of scatter graphs to determine which quantity-quality relationships had the highest degree of linear association. To facilitate this analysis a program was developed (33) which, given the recorded hydrographs, pollutographs, and specific characteristics for each watershed, generated a number of quantity-quality relationships, both graphically and in tabular form. The analysis also made extensive use of transformed variables, particularly the transformation to logarthims.

Step (2) In order to more precisely quantify the quantity-quality relationships derived in Step (1) a statistical analysis was performed to determine which of these screened relations had the highest correlative association. The correlation coefficient is the most commonly used statistical parameter for measuring the degree of association of two linearly dependent variables. It is defined as: (34, 35)

$$R = \frac{\Sigma X_i Y_i - N \bar{x} \bar{y}}{S_x S_y (N - 1)}$$

where: R is the correlation coefficient; X_i and Y_i are the dependent variables; N is equal to the number of data points; S_x and S_y are the standard deviations of X_i and Y_i respectively; and $\bar{x}$ and $\bar{y}$ are the arithmatic means of x and y

The correlation coefficient varies from an absolute value of 1.0 to 0.0 with 1.0 indicating that all points will fall on a straight line and a value of 0 meaning that there is no association.

By choosing the quantity-quality relationship which yielded the highest value of R, the best linear association for each relation was determined analytically. The results of this analysis then produced the best of correlative association for each watershed. These associations were used in Step 3 to develop a regression equation describing their relationships.

Step (3) A simple linear regression was then performed on quantity-quality data associations developed. The purpose of the regression was to reduce the data to an equation of the general form,

$$y = c_1 x + c_2$$

where: y is equal to some measure of runoff quality; x is equal to some measure of runoff quantity; and c_1 and c_2 are coefficients developed from the regression analysis.

In order to test the significance of the derived equation, a statistical test which employs the standard deviation of the correlation coefficient (S_r) was used. The standard deviation is defined (35) as:

$$Sr = \frac{1 - R^2}{\sqrt{N}}$$

where: R and N are as previously defined. The basic purpose of the statistical test was to determine the degree to which the correlation coefficient (R) was different from zero. If both limits ($R \pm S_r$) are of the same sign as R, it is concluded by this test that R is significantly different from zero. Values of R and the sign of the limits are presented on Table I- 7 . The results of Step (3) were a set of runoff quantity-quality equations for each study watershed.

In order to determine correlative associations between runoff quality-quantity and watershed characteristics, Steps 1 through 3 were repeated to determine how the quantity-quality equations vary with changes in watershed or land-use characteristics. These variations were then reduced, by regression analysis, to a set of equations which were used to predict runoff quality for any combination of runoff quality and watershed characteristics.

Results

Using the screening program previously discussed, it was determined that only two quantity-quality relationships had reasonable linear associations. These were:

1) the cumulative runoff volume (FT^3) versus cumulative pollutant load (lbs.) and

2) the logarithm of cumulative runoff volume (FT^3) versus the logarithm of cumulative pollutant load (lbs.)

For all storm events and pollutants examined, a reasonably straight line or linear relationship was found to exist. This relationship was also found to hold true when the total cumulative runoff versus total pounds of pollutant generated for all runoff events for a particular watershed was graphically plotted. As a result of this graphical analysis it was decided that the total cumulative volume-pounds relationship would be used as a basis for a more detailed statistical analyses.

To compare the quantity - quality relationships between the different watersheds, and hence different surface and land use characteristics being studied, it was necessary to reduce the data to a common format. Because each watershed is different in terms of its drainage area, ground slope, soil type, surface flora, etc., it is obvious that different runoff volumes and pollutant quantities would be produced even if other factors such as land use and rainfall were equal. For this reason, runoff volumes and pounds of pollutant were converted to inches per acre of runoff and average pounds per acre of pollutant generated during each storm event. A summary of total stormwater quantity-quality values for each storm event is presented in Appendix A.

The correlation analysis results presented in Table I-7 indicated that the logarithmic transforms (col.2) of total cumulation runoff volume (inches) and total cumulative pollutant load (pounds) yielded the highest degree of linear correlation. Using this relationship, regression analyses were performed to generate best fit equations for total suspended solids, biochemical oxygen demand, chemical oxygen demand, Kjeldahl-N, NH_3-N, total phosphates, and dissolved oxygen for each watershed. This analysis consisted of first transforming the variables, total runoff in inches and total pounds in pounds per acre, to their logarithm values and then performing a linear regression on the variables.

The resulting equations in linear form are given as:

$$\log y = \log a + b \log x$$

TABLE I-7

CORRELATION COEFFICIENTS FOR DETERMINATION OF REST FIT EQUATION

	POLLUTANTS AND CORRELATION COEFFICIENT MATRIX FOR QUANTITY - QUALITY													
	TSS		B.O.D.		C.O.D.		N_3H-N		KJEL-N		PHOSPHATES		D.O.	
WATERSHED	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
1. 39th and Holdrege Lincoln, Neb.	.91	.97	.17	.81	.92	.94	—	—	—	—	—	—	—	—
2. 63rd and Holdrege Lincoln, Neb.	.96	.92	.17	.26	.87	.75	—	—	—	—	—	—	—	—
3. 78th and A Lincoln, Neb.	.84	.89	.98	.92	.79	.91	—	—	—	—	—	—	—	—
4. Third Fork Durham, N.C.	.94	.88	.96	.91	.96	.92	—	—	.88	.80	.97	.95	—	—
5. P-10 Woodlands, Tex.	.98	.98	—	—	1.00	.98	.82	1.00	.97	.98	1.00	1.00	—	—
6. P-30 Woodlands, Tex.	.95	.97	—	—	1.00	1.00	.78	.97	1.00	1.00	1.00	.99	1.00	1.00
7. Hunting Bayou Houston, Tex.	.99	.98	—	—	.94	.93	.98	.97	1.00	.90	.96	.87	—	—
8. Texas Lubbock, Tex.	.79	.81	.95	.77	.20	—	—	—	—	—	.97	.96	—	—
9. Selby Street San Francisco, Ca.	.95	.93	.97	.90	.98	.87	.14	.40	.98	.87	.37	.22	—	—

TABLE I-7 (Contd.)

CORRLETION COEFFICIENTS FOR DETERMINATION OF REST FIT EQUATION

where:

(1) x (cumulative runoff) correlated to y = (cumulative pollutant load).

(2) x (log cumulative runoff) correlated to y = (log cumulative pollutant load).

which transforms to the much simpler function: (35)

$$y = ax^b$$

where y is the total pounds of pollutant, x is the total runoff in inches, and a and b are the regression coefficients generated by the analysis. Table I-8 presents a summary of the generated regression coefficients a and b and the correlation coefficients for the nine study watersheds. As the correlation coefficient approaches 1.00, a better correlation between variables is evidenced.

To evaluate the statistical significance of the regression analyses, a test utilizing the standard deviation of the correlation coefficient (S_r), as previously discussed in the Methodology Section of the report, was performed. The results of these analyses are presented in Table I-9 and indicate a generally high degree of significance.

In attempting to relate these regression equations to the different surface characteristics found in each watershed, a number of parameters were examined. The only parameter which appeared to produce a linear association to the runoff quantity and quality was the percent imperviousness of each watershed. In general, as the percent imperviousness of a watershed increases, the pollutant generated by a specific runoff event was found to increase. This relationship is graphically illustrated in Figure I-1 for total suspended solids. Therefore, using percent impervious a statistical analysis was conducted in an attempt to relate this parameter to the quantity-quality equations developed above.

The result of this analysis indicates a strong correlation between variations in the imperviousness of a basin and the previously defined coefficient a. Coefficient b, on the other hand, exhibits no such correlation, and seems to cluster around a value approaching 1.0. Table I-10 presents the statistics of this analysis for both coefficients a and b. From this analysis a final set of runoff quantity-quality functions is presented in Table I-11. Given the percent imperviousness of a basin and the runoff volume in inches, these functions generate total pollutant load in pounds per acre.

TABLE I-8

SUMMARY OF REGRESSION COEFFICIENTS* DERIVED FROM THE QUANTITY/QUALITY ANALYSES

WATERSHED	NUMBER OF EVENTS	TSS		B.O.D.(5)		C.O.D.		KJELDAHL-N		NH_3-N		TOTAL PO_4		D.O.	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b
1. 39th and Holdrege Lincoln, Neb.	18	185.88	1.19	3.69	.65	38.81	.84	—	—	—	—	—	—	—	—
2. 63rd and Holdrege Lincoln, Neb.	14	156.26	1.14	2.89	.35	26.24	.64	—	—	—	—	—	—	—	—
3. 70th and A Lincoln, Neb.	10	155.75	.97	1.08	.71	15.46	.95	—	—	—	—	—	—	—	—
4. Third Fork Durham, N.C.	35	222.66	1.05	13.15	1.18	35.78	.99	.08	.73	—	—	.19	1.08	—	—
5. P-10 Woodlands, Tex.	4	7.16	.75	—	—	18.51	1.14	.25	.92	.02	1.01	.02	.99	—	—
6. P-30 Woodlands, Tex.	5	38.94	.77	—	—	12.49	.89	.39	.99	.02	.77	.02	.67	1.6	1.09
7. Hunting Bayou Houston, Tex.	4	49.77	1.16	—	—	19.85	.87	1.17	1.39	.79	1.63	.2	1.02	—	—
8. Texas Lubbock, Tex.	11	763.63	1.54	27.65	1.70	—	—	—	—	—	—	.06	1.41	—	—
9. Selby Street San Francisco, Ca.	7	51.19	.72	4.77	.31	26.52	.54	.63	.47	.12	.38	.11	.19	—	—

TABLE I-8
(contd.)

* Coefficients given are for the equation $Y = ax^b$, where y is equal to the total pounds per acre generated and x is equal to the total runoff per event in inches. Where no values of a or b are presented, insufficient data was available for analysis.

TABLE I-9

SUMMARY OF TEST FOR STATISTICAL SIGNIFICANCE*

WATERSHED	T.S.S.	B.O.D.	C.O.D.	NH_3-N	K-N	TOTAL P	D.O.
1	.94	.51	.85				
2	.80	-.58	.39				
3	.68	.74	.76				
4	.49	.80	.83		.59	.89	
5	.92		.92	1.00	.92	1.00	
6	.88		1.00**	.88	1.00**	.96	1.00
7	.92		.72	.84	.60	.51	
8	.42		.17			.87	
9	.50	.69	.60	-.62	.68	-.80	

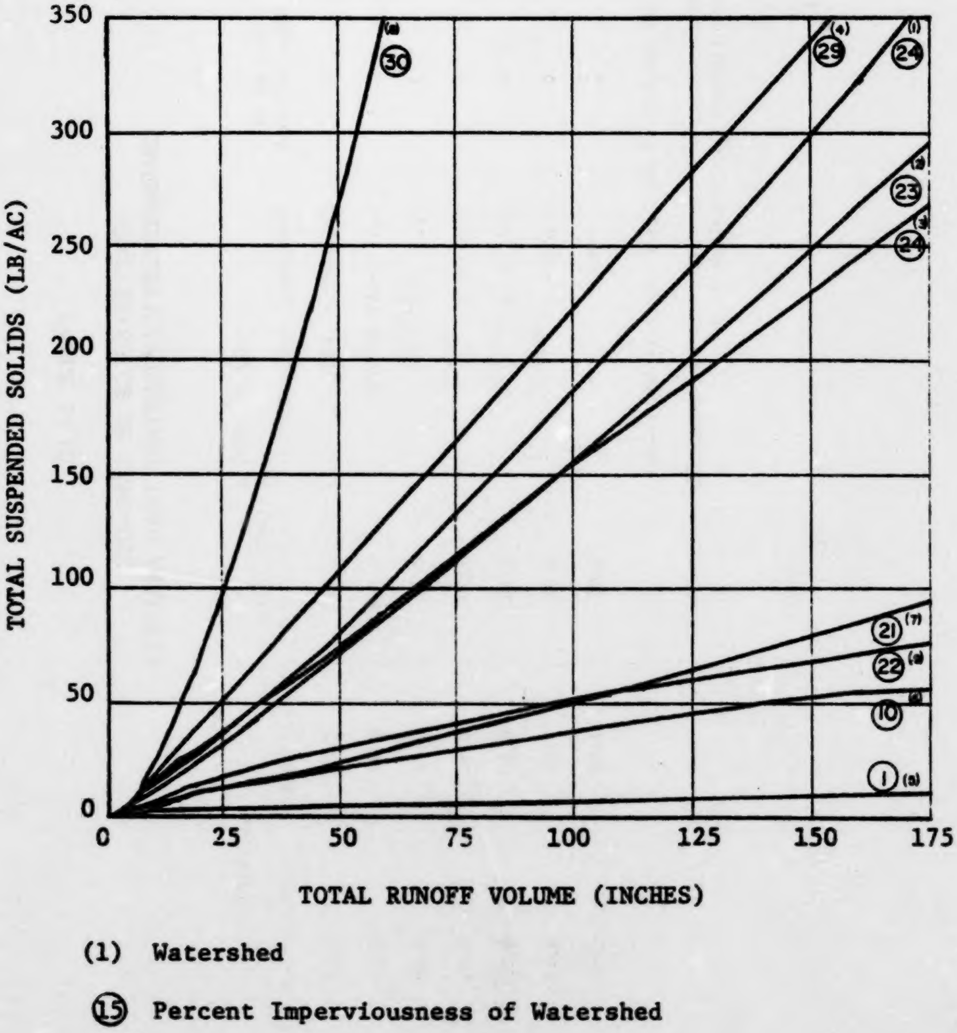
---

* Values Given are for (R-3Sr) only. The reason for this is that all values of R are positive and therefore only -3Sr will yield a change in sign. A negative value indicates a relationship which is not statistically significant given the data used.

** Because only two (2) events were recorded these relationships cannot be considered as being statistically significant.

FIGURE I-1

CHANGE IN THE QUANTITY/QUALITY OF STORMWATER RUNOFF AND PERCENT IMPERVIOUS



Reproduced from best available copy.

TABLE I- 10

STATISTISTICS OF LAND-USE CHARACTERISTIC/POLLUTANT LOAD ANALYSIS

Pollutant	Number of Observations*	COEFFICIENT A Functional Relationship	Correlation Coefficient	COEFFICIENT B Mean Value	Standard Deviation
T.S.S.	9	$I/(.1362 + .00384(I))$	0.99	1.05	0.27
B.O.D.	6	$7.3971-(83.0334/I)$	0.76	0.82	0.53
C.O.D.	8	$12.71\ e^{.0315(I)}$	0.72	0.86	0.19
KJELDAHL-N	5	$0.01369\ e^{.0888(I)}$	0.90	0.90	0.34
NH_3-N	4	$0.2437\ e^{.0438(I)}$	1.00	0.95	0.52
TOTAL PO_4	6	$0.01349\ e^{.09677(I)}$	0.94	0.89	0.42
D.O.	3	1.6**	1.00	1.09	——

Where: I is the percent of the basin which is impervious

* Number of study watersheds for which data was available.
** D.O. is a function of runoff volume only

TABLE I- 11

SUMMARY OF POLLUTANT YIELD (LB/AC)
QUANTITY/QUALITY EQUATIONS

GENERAL EQUATION: $\text{Load} = a * x^{b}$

1. **T.S.S.:**

   $a = I/(.1362 + .00384(I)$

   $b = 1.05$

2. **B.O.D.(5):**

   $a = 7.3971\ (83.0334/I)$

   $b = .82$

3. **C.O.D.:**

   $a = 12.71e^{.0315(I)}$

   $b = .86$

4. **KJELDAHL-N:**

   $a = .01369e^{.0888(I)}$

   $b = .90$

5. **NH_3-N:**

   $a = .2437e^{.0438(I)}$

   $b = .95$

6. **Total Phosphates:**

   $a = .09677(I)$

   $b = .89$

7. **Dissolved Oxygen:**

   $a = 1.6$

   $b = 1.09$

WHERE:

x is the total runoff in inches

I is the percentage of the basin which is impervious

a and b are regression coefficients

SWMM Application to Selected Watersheds

Introduction and Model Description

The Storm Water Management Model (SWMM) simulates real or design storm events on the basis of rainfall (hyetograph) inputs and system (catchment, conveyance, storage/treatment, and receiving water) characteristics to predict quality and quantity of storm runoff. Outputs include hydrographs (flow versus time), pollutographs (concentration of pollutant versus time) and mass flow rate (pounds per minute versus time). Generating algorithms for this output are organized program groups or "Blocks". These Blocks include the following: (26)

1) The Executive Block assigns logical units (disk/tape/drum), determines the block or sequence of blocks to be executed, and on call, produces graphs of selected results on the line printer.

2) The Combine Block allows the manipulation of data sets (files stored on offline devices) in order to aggregate results of previous runs for input into subsequent blocks. In this manner large, complex drainage systems may be partitioned for simulation into smaller segments.

3) The Runoff Block computes the stormwater runoff and its characteristics for a given storm event for each subcatchment within a drainage basin and stores the results in the form of hydrographs and pollutogrpahs at inlets to the main drainage system. It accomplishes this by accepting an artibtrary rainfall hyetograph (real or design and making a step by step accounting of rainfall infiltration losses in pervious areas (Horton's equation), surface detention overland or channel flow (Manning's equation), and the contaminants washed into inlet points leading to the calculation of a number of inlet hydrographs and pollutographs.

   The Runoff Block will allow each drainage basin to be divided into a maximum of 200 subcatchment areas. These, in turn, may drain into a maximum of 200 channels or pipes, which finally connect to the inlet points for the Transport Block.

   Where recorded hydrographs or pollutographs are available, calculated hydrographs and pollutographs can be "calibrated" by adjustment of input variables such as catchment*, Horton's equation coefficients, retardance coefficients, etc.

4) The Transport Block sets up pre-storm conditions by computing dry weather flow and infiltration and distributing them throughout the conveyance system. The block then performs its primary function of flow and quality routing, picking up the runoff results, and producing combined flow hydrographs and pollutographs for the total drainage basin and at selected outflow points.

   The Transport Block has available a data block library of pipe (closed conduit) and open channel cross-sections. Typical input requirements for these cross-sections include bottom width, side slope, and maximum depth for trapezoidal channels or inside diameter and water depth for closed conduits.

   Calibration of Transport Block output can be accomplished by adjustment of Manning's n and other conveyance parameters.

5) The Storage Block uses the output of the Transport Block and modifies the flow and characteristics at a given point or points according to the predefined storage and treatment facilities provided. Costs associated with the construction and operation of the storage/treatment facilities are computed.

6) The Receiving Water Block accepts the output of the Transport or Runoff Blocks directly, or the modified output of the Storage Block, and computes the resulting hydrodynamics and concentration distributions in the receiving river, lake, estuary, or bay.

A graphical illustration of the interrelationship of these "blocks" is presented on Figure I-2.

Descriptions of Watersheds and Subcatchments

Subbasins analyzed in this study include those areas drained by significant tributaries and storm sewers to the following streams:

Spring Creek (Segment 1008)*
Cypress Creek (Segment 1009)*
Lake Houston (Segment 1002)
Buffalo Bayou
White Oak Bayou
Brays Bayou
Sims Bayou
Greens Bayou
Carpenters Bayou

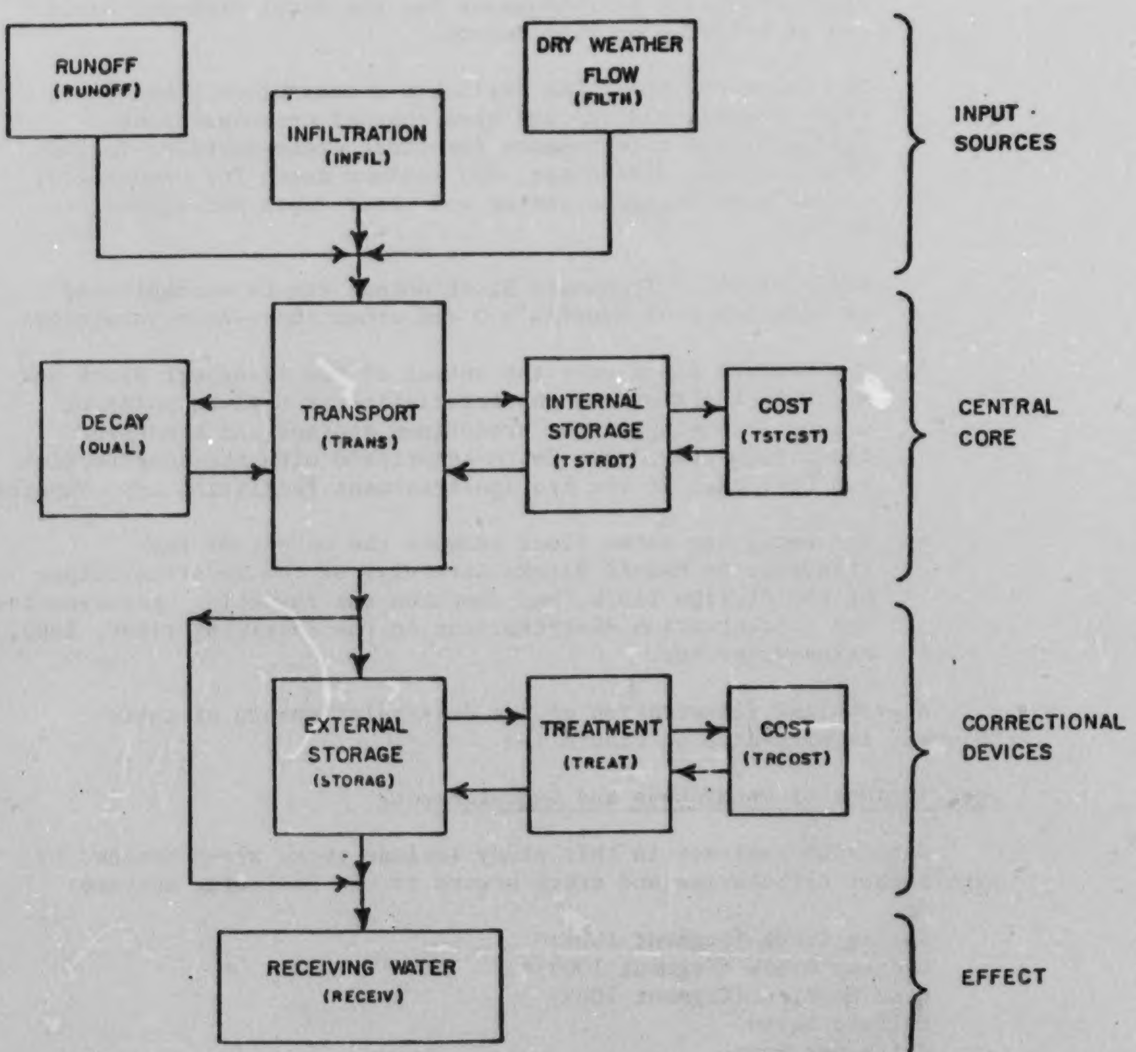
---

* Segment for which hydrographs and pollutographs are to be provided.

FIGURE I-2

OVERVIEW OF MODEL STRUCTURE

(FROM THE SWMM USERS MANUAL)


RUNOFF
(RUNOFF)
INFILTRATION
(INFIL)
DRY WEATHER FLOW
(FILTH)
INPUT SOURCES
DECAY
(QUAL)
TRANSPORT
(TRANS)
INTERNAL STORAGE
(TSTRDT)
COST
(TSTCST)
CENTRAL CORE
EXTERNAL STORAGE
(STORAG)
TREATMENT
(TREAT)
COST
(TRCOST)
CORRECTIONAL DEVICES
RECEIVING WATER
(RECEIV)
EFFECT

Note: Subroutine names are shown in parentheses.

Lower San Janinto River (below Lake Houston) (Segment 1001) *
Burnett Bay (Segment 2430)
Scott Bay (Segment 2429)
Black Duck Bay (Segment 2428)
Tabbs Bay (Segment 2427)
Houston Ship Channel (Segments 1005, 1006*, and 1007*)
Armand Bayou
Clear Lake (Segment 2425)
Clear Creek (Segments 1101 and 1102)*
Dickinson Bayou (Segments 1103 and 1104)

All mapped outputs are shown on Exhibit I, the one-inch to two-mile subcatchment map.

Mapping of the entire 208 area resulted in the delineation of approximately 290 subcatchments for the Nonpoint Source Analysis. Exhibit I also shows the 290 subcatchments. The subcatchments were defined based on the hydraulic characteristics of the land within each watershed. The physical characterictics such as area, channel size, slopes, and pipe sizes were determined from available mapped data. Land use information by subcatchment for 1975, 1983, 1990, and 1995 was supplied by the H-GAC.

Design Storm Development

A design storm, as defined here, is simply a synthetized storm whose properties are based on the statistical analysis of rainfall records from a given raingage, area or region. The storm events developed here are for one month, six months, and two years return frequencies with a standard duration of one hour and are from data contained in the U.S. Weather Bureau Technical Paper No. 40. (36)

To develop the total rainfall volume for one month and six month - one hour events it was necessary to extrapolate from the quantities given in TP-40, which are only given for frequencies of one year or larger. To accomplish this, rainfall qualtities for the one year, two year, and five year - one hour event were determined from TP-40 and plotted on log-log paper, as shown on Figure I-3. The straight line drawn through these points is given by the equation,

$$\text{TOTAL RAINFALL (INCHES)} - 2.00\ (\text{FREQUENCY})^{0.23}$$

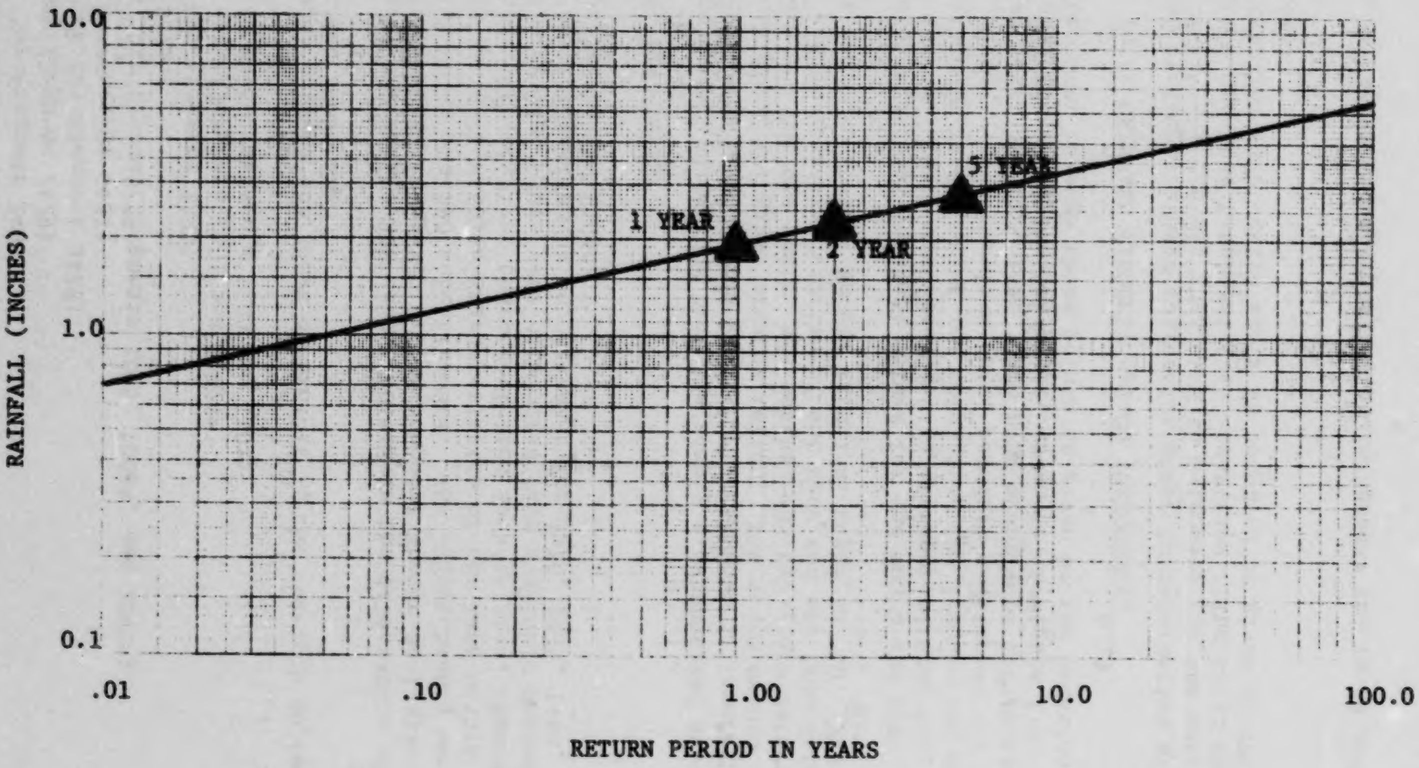
as determined by simple linear regression after transformation of variables. This equation was then used to determine the one month and two month - one hour total rainfall quantities. The total rainfall quantities for each design storm as computed or given in TP40 are as follows:

---

* Segments for which hydrographs and pollutographs are to be provided.

FIGURE I-3

RAINFALL FREQUENCY CURVE FOR HOUSTON AREA
1-HOUR DURATION (36)



DESIGN STORMS

FREQUENCY	TOTAL RAINFALL (INCHES)
1 month	1.13
6 month	1.71
2 year	2.35

A uniform time-intensity distribution was used for each design storm. This means, in this particular case, that the rainfall intensity (inches per hour) will be uniform throughout the event, lasting one hour, and that it will be numerically equal to the total rainfall volume given above.

Infiltration Allowance

Infiltration is the passage of water through the soil surface into the soil (38), normally starting at a high rate and decreasing during rainfall to a lower constant. This process occurs in a three step sequence: 1) entry of water through the soil surface, 2) transmission through the soil and 3) the filling of the storage capacity of the soil. Infiltration will be limited to the lowest transmitted rate encountered by the water. Therefore, as a storm event progresses the rate of infiltration will decrease as the available capillary-pore spaces are filled. This will continue until the infiltration rate reaches value minimum/value typical percolation of the soil complex. The rate of infiltration during the early phases of a storm is less if the capillary pores have been partially or completely filled from a previous storm. The average infiltration capacity, f_c, during a time interval is taken to be the value at the center of the time interval (t + 0.5 t) and is calculated by the SWMM using Horton's equation: (26, 27, 38, 35)

$$f_c = (f_i - f_o)e^{-kt^*} + f_o$$

where

f_c = infiltration capacity at time t*;

f_i = maximum infiltration rate;

f_o = minimum infiltration rate;

k = decay rate; and

t* = time from the start of rainfall to the midpoint of the time interval t + 0.5

Horton's equation has been found to fit a large number of experimental infiltration capacity curves obtained from different soils with different types of vegetal cover and in widely separated regions. The equation was derived from experimental infiltration tests in which the supply of water exceeds the infiltration capacity. Therefore, a limitation of the equation is that rainfall intensity must always exceed the infiltration capacity. In naturally occurring rainfall, the rainfall intensity can be less than the infiltration capacity and periods of zero runoff can occur.

In theory the parameters used in Horton's equation are all variable. However, the variability of f_o and k are small when compared to that exhibited by f. In practice, therefore, f and k are considered to be constant for a particular soil complex, while f_i varies as a function of both soil characteristics and actecedent moisture present.

A first step in determining typical values for f_i, f_o, and k to be used was an analysis of predominant soil types found in the H-GAC 208 Planning Area.

Soils in the H-GAC planning area are predominantly clays, clay loams, and fine sandy loams that have low to very low permeabilities. Soils in the area north of Buffalo Bayou are composed of fine sand loams and clays. South of Buffalo Bayou the soils consist of clay loams (Beaumont Clay) and are treeless in their natural state. (39)

Table I-12 presents a summary of soils and their characteristics. To facilitate analyses, the soils found roughly north and south of Buffalo Bayou, Figure I-4, will henceforth be referred to as Type I and Type II soils, respectively. The marked difference in characteristics, particularly permeability, between these soil types dictated that two sets of infiltration parameters be developed.

The methodology used to determine infiltration parameters for Type I and Type II soils involved the following steps:

1) An analysis of soil characteristics to determine an estimate of minimum infiltration rate applicable to Type I and II soils.

2) The use of the SWMM to model recorded rainfall-runoff events for selected watersheds with the purpose of deriving a set of maximum infiltration rates (f_i) and corresponding indices of soil moisture, an estimate of the decay content (k).

3) Estimating the antecedent moisture existing at the start of each storm event evaluated in Step 3. The most common index of antecedent moisture is based on antecendent precipitation. The rate at which moisture is depleted is proportional to the amount of storage in a particular

TABLE I-12

CHARACTERISTICS OF MAJOR SOIL TYPES IN H-GAC 208 PLANNING AREA (40)

TYPE I

Soil name and map symbol	Depth In	Permeability In/hr	Available water capacity In/in
Addicks: *			
Ad--------------	0-11	0.6-2.0	0.15-0.24
	11-49	0.6-2.0	0.15-0.24
	49-78	0.6-2.0	0.15-0.24
Clodine: *			
Cd--------------	0-12	0.6-2.0	0.15-0.20
	12-29	0.6-2.0	0.15-0.20
	29-72	0.6-2.0	0.12-0.20
Gessner: *			
Ge, [1]Gs---------	0-16	0.6-2.0	0.10-0.15
	16-80	0.6-2.0	0.15-0.20
Hockley:			
HoA, HoB--------	0-23	2.0-6.0	0.10-0.15
	23-50	0.6-2.0	0.12-0.17
	50-80	0.2-0.6	0.10-0.15
Urban land part.			
Nahatche:			
Na--------------	0-18	0.6-2.0	0.10-0.15
	18-30	0.6-2.0	0.10-0.15
	30-60	0.6-2.0	0.10-0.15
Segno:			
SeA, SeB--------	0-13	0.6-2.0	0.10-0.15
	13-42	0.2-0.6	0.10-0.15
	42-75	0.2-0.6	0.08-0.12

TABLE I-12
(cont'd)

TYPE I

Soil name and name symbol	Depth In	Permeability In/hr	Available water capacity In/in
Urban land: Ur.			
Vamont: VaA, VaB--------	0-8	0.06-0.2	0.15-0.2
	8-70	< 0.06	0.15-0.2
	70-80	< 0.06	0.15-0.2
Wockley: ** Wo---------------	0-22	2.0-6.0	0.15-0.20
	22-60	0.2-0.6	0.12-0.18

TABLE I- 12
(cont'd)

TYPE II

Soil name and map symbol	Depth In	Permeability In/hr	Available water capacity In/in
Aldine:			
Am	0-10	0.6-2.0	0.13-0.20
	10-19	0.2-0.6	0.13-0.20
	19-60	< 0.06	0.15-0.20
Aris:			
Ap	0-21	0.6-2.0	0.11-0.15
	21-28	0.2-0.6	0.12-0.17
	28-60	< 0.06	0.12-0.18
	60-78	< 0.06	0.12-0.18
Atasco:			
AtB	0-16	0.6-2.0	0.14-0.18
	16-19	0.2-0.6	0.15-0.19
	19-60	< 0.06	0.15-0.22
Beaumont: *			
Ba	0-21	0.06-0.2	0.15-0.20
	21-59	< 0.06	0.15-0.20
	59-73	< 0.06	0.15-0.20
Bernard: *			
Bd	0-6	0.06-0.2	0.15-0.20
	6-34	< 0.06	0.12-0.18
	34-65	< 0.06	0.15-0.20
Edna:			
Ed	0-5	0.6-2.0	0.10-0.15
	5-41	< 0.06	0.15-0.20
	41-72	< 0.06	0.15-0.20
Harris:			
Ha	0-20	0.06-0.2	0.02-0.20
	20-45	< 0.06	0.01-0.10
	45-64	< 0.06	0.01-0.10
Ijam:			
Is	0-8	< 0.06	0.10-0.12
	8-60	< 0.06	0.10-0.12
Kaman:			
Ka	0-70	< 0.60	0.15-0.20

TABLE I-12
(cont'd)

TYPE II

Soil name and map symbol	Depth In	Permeability In/hr	Available water capacity In/in
Katy:			
Kf-------------	0-28	0.6-2.0	0.15-0.20
	28-65	<0.2	0.12-0.18
Lake Charles: *			
LcA, LcB-------	0-22	0.06-0.2	0.15-0.20
	22-74	< 0.06	0.15-0.20
Midland: *			
Md-------------	0-7	0.06-0.2	0.20-0.22
	7-72	< 0.06	0.18-0.20

* Most predominant type.
** Predominant type in Spring Creek Watershed.

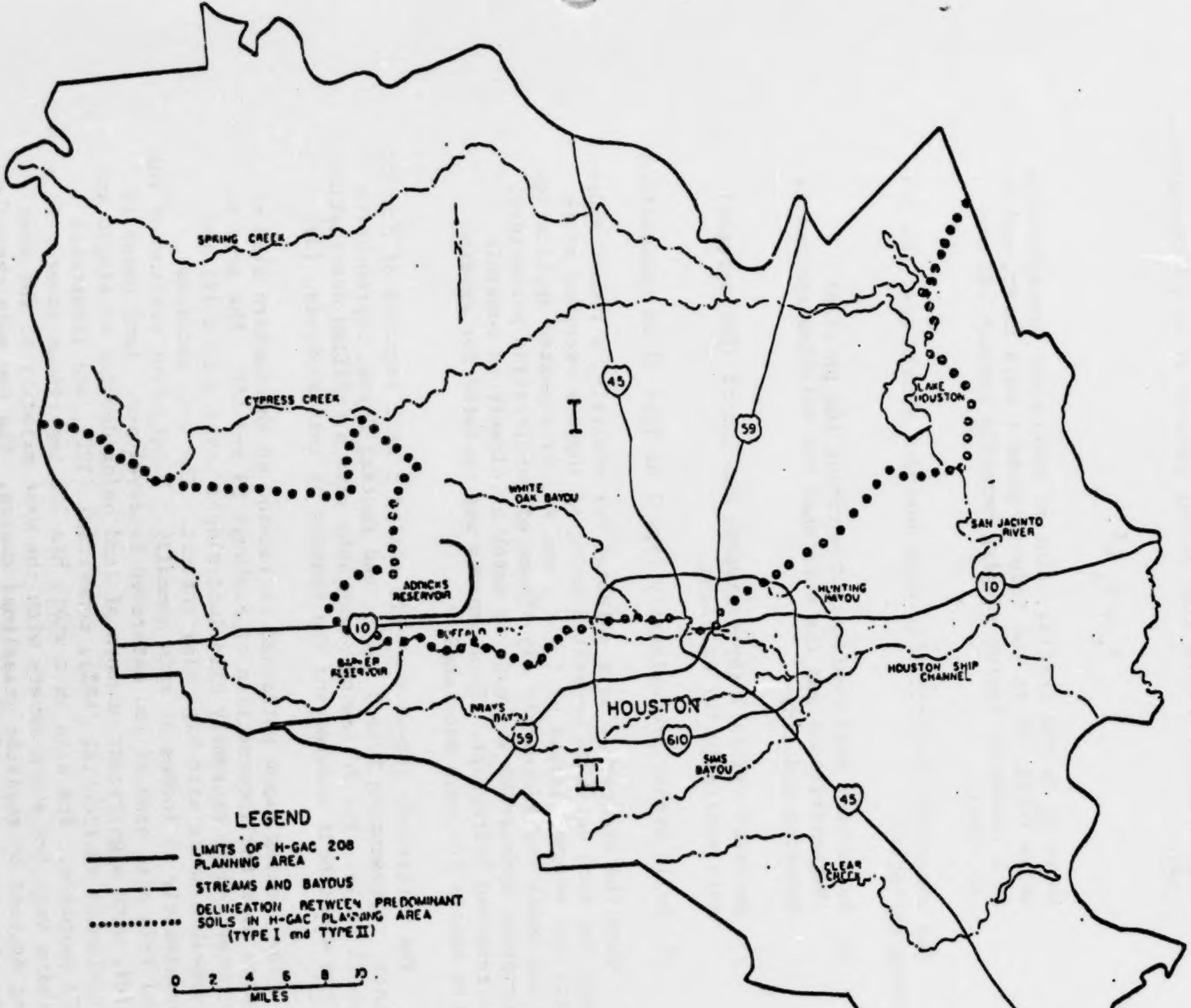

SPRING CREEK
N
CYPRESS CREEK
I
45
59
LAKE HOUSTON
WHITE OAK BAYOU
SAN JACINTO RIVER
ADDICKS RESERVOIR
HUNTING BAYOU
10
BUFFALO BAYOU
BARKER RESERVOIR
HOUSTON SHIP CHANNEL
HOUSTON
610
BRAYS BAYOU
II
SIMS BAYOU
CLEAR CREEK
LEGEND
LIMITS OF H-GAC 208 PLANNING AREA
STREAMS AND BAYOUS
DELINEATION BETWEEN PREDOMINANT SOILS IN H-GAC PLANNING AREA (TYPE I and TYPE II)
0 2 4 6 8 10
MILES

FIGURE I-4

DELINEATION OF MAJOR SOIL TYPES
IN H-GAC 208 PLANNING AREA

basin. The soil moisture should therefore decrease logarithmically with time during periods of no precipitation. (38)

$$I_t = I_o k^t$$

where I_o is the initial value of antecedent precipitation index (API), it is the reduced value t days later, and k is a recession factor ranging normally between .85 and .45. (38)

The watersheds selected for this analysis should meet the following criteria:

1) Sufficient data available describing the physical characteristics and the watershed for detailed stormwater quantity modeling

2) Recorded rainfall (hyetographs) and runoff (hydrographs) data available for modeling

3) Soils either predominantly Type I or Type II in composition

Once the watersheds were selected for analysis, a runoff hydrograph for each was then generated using as input a recorded storm event and assumed values of f_i, f_o, and k. By repeated application of the model and systematic adjustment of infiltration parameters, a computed hydrograph was made to match as closely as possible the recorded hydrograph. This process was repeated for several storm events for each watershed.

The watersheds chosen for this analysis were segments of Panther Branch, representing Type I soils, and Hunting Bayou, representing Type II soils. The following paragraphs give a detailed description of the watersheds modeled and the results of this analysis. (29)

The Hunting Bayou watershed is located on the eastern side of Houston near the intersection of Highways 59 and 610. The area is characterized by extremely mild land slopes (typically 0.1%) and impermeable soils with high clay content. The area receives approximately 45 inches of rain annually. Ninety-four percent of the total 1976 acre area of the watershed is developed. Land usage is varied, with significant amounts of land being devoted to single and multi-family residential (48%), commercial (32%), and industrial (14%) purposes. The area as a whole has 21% impervious cover. It contains very few storm sewers with the vast majority of the area being drained by roadside grasslined swales. The two main channels of Hunting Bayou are essentially trapezoidal with low flow channels.

The banks and channel beds are earthen and are lined with vegetation which varies in density from moderate to very heavy depending upon the season of the year and maintenance schedules.

The area modeled on Hunting Bayou consists of the entire watershed upstream of the U.S. Geological Survey (USGS) gaging station No. 08075760 at Falls Street (Station H-20). This station, which has been in operation since 1964, continuously records flood hydrographs and rainfall. In the past, there has also been a gaging station upstream (USGS No. 08075750) at the Cavalcade Street Bridge on the south tributary of Hunting Bayou (Station H-10). This station was discontinued in 1973.

Most of the input data concerning the Hunting Bayou drainage system was taken from existing engineering maps of the area, and site inspection of the study area. A map showing the subcatchments and drainage network which were used as input to the model is shown in Exhibit 1. Five storms were modeled initially. The rainfall data tor these storms were obtained from reports published by the U.S. Geological Survey. (32)

The total Hunting Bayou drainage area of 1976.8 acres was divided into 24 subcatchments ranging in area from 25 acres to 138 acres. The drainage system includes 23 gutters and pipes in the Runoff Block and 44 manholes and conduits in the Transport Block.

The subcatchment, gutter and pipe, and transport element data were essentially identical for all runs. The storm-related data included rainfall and infiltration coefficients. Infiltration rates were estimated from the observed rainfall and runoff. Initially, the antecedent precipitation index was used to establish a starting infiltration rate but this parameter proved to be unreliable as a deterministic predictor and was subsequently discarded. Therefore, all infiltration rates were originally estimated and then calibrated by consecutive modeling runs.

Comparisons of observed and computed hydrographs for five storm events which were modeled indicated that overall agreement was reasonable. The average absolute error in volume of runoff was 26% of the observed value, while the average error in peak flow prediction was 20% of the observed peak. The temporal agreement of the hydrographs was very good. For instance the times of peak flow agreed within ten minutes in four of the five instances. The average error was 22 minutes. It was also noted that the computed values tended to predict faster returns to low flow conditions than were actually observed.

For a further delineation of the work performed on the Hunting Bayou watershed as well as the Panther Branch watershed, the reader is referred to the technical report prepared by Espey, Huston & Associates (September, 1976) as partial completion of the requirements of EPA Grant No. 802433. (41, 42, 29)

The data input to the SWMM for the Panther Branch drainage system was developed from existing engineering maps and numerous site inspections of the watershed. Because of the low relief, drainage area boundries had to be visually determined in some area.

Panther Branch is an intermittent stream with major no-flow periods occurring during the summer months. A flow gaging station, P-30 (USGS No. 08068450) was established near the lower end of the Woodlands site in May 1972. The drainage area upstream of the gage is 54.39 square kilometers (33.8 square miles).

Panther Branch and its tributary, Bear Branch, form the principal drainage system upstream of the developing areas in The Woodlands. A stream stage recorded, station P-10, is located below the confluence of Bear and Panther Branches and has a drainage area of 15.10 square miles. The drainage area of P-10 is undeveloped forest land while the P-30 drainage area includes Phase I development of The Woodlands.

The modeled drainage system for Panther Branch (21,607 acres) was divided into 57 subcatchments ranging from 21 acres to 1366 acres. The input parameter called "width of subcatchment" has been defined as the width over which overland flow occurs. Values for this parameter were first estimated by the method described in the SWMM User's Manual. These values were subsequently reduced by approximately 40% to achieve calibration.

Five storm events on Panther Branch have been modeled. Similar to the data for Hunting Bayou, all subcatchment, gutter and transport element data for Panther Branch were identical for all runs. The storm-related data was comprised of rainfall and infiltration coefficient data. (41, 42, 29)

Observed and computed total flow volumes and peak flow rates were compared and the computed flow peaks and volumes were found to agree well with the observed flows; the average absolute error in the volume of runoff was 14 percent of the observed peak. The temporal distribution of runoff between observed and computed hydrographs was good except for the storm events of October 28, 1974, and November 24, 1974, when the flow peaks between observed and computed hydrographs were approximately three hours apart.

An analysis of the calibrated infiltration parameters derived from the analysis of the Hunting Bayou and Panther Branch watersheds shows a marked variation in the maximum infiltration rate (f_i) with both antecedent precipitation, soil moisture, and soil type.

From this analysis a set of infiltrations parameters were derived for both Type I and II soils. The constant f_o and k are given as follows:

Type I: $f_o = .06$ in/hr; $k = .00115$ 1/sec

Type II: $f_o = .02$ in/hr; $k = .001155$ 1/sec

Values of f_i for each soil type are presented as a set of multivariant curves shown in Figure I-5. The first curve relates the number of antecedent dry days to the API*, while the second curve relates the API to the initial or maximum infiltration rate (f_i). Using these curves, f_i can be quickly determined for a wide range of antecedent dry days. In this analysis 10 dry days were chosen. From this, the maximum infiltration rates to be used are given as follows:

Type I: $f_i = 2.0$ in/hr

Type II: $f_i = 1.4$ in/hr

Water Quality Input Data

Total Pollutant Loads were determined using the quantity-quality equations previously derived, the general form of which is:

$$y = ax^b$$

where: y is the total pounds of pollutant generated per acre

x is the total runoff generated per acre; and

a & b are coefficients which are a function of the imperviousness of the watershed and type of pollutant

The percent imperviousness of each watershed was determined by using the percentage of specific land uses found in each watershed and values for average percent impervious for specific land uses. The general form of the equation used in determining average percent imperviousness for each subcatchment is given by:

$$I = (l_1 * i_1) + (l_2 * i_2) + \ldots + (l_n * i_n)$$

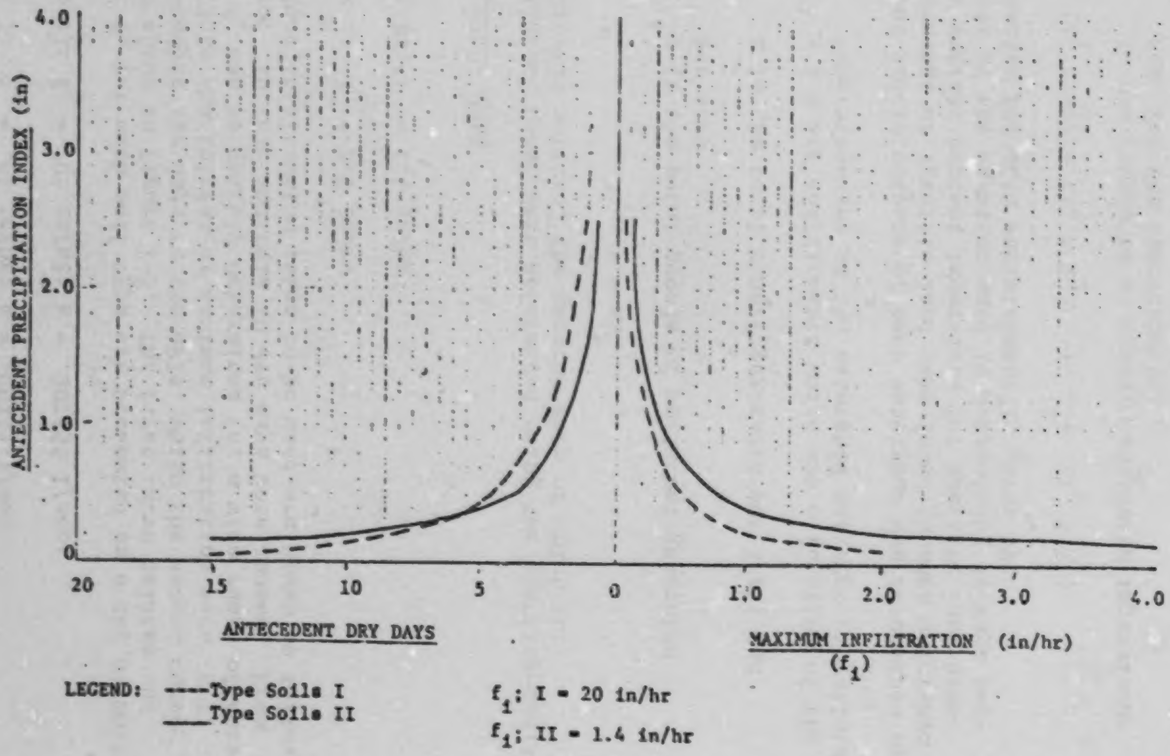
where: I is the composite or average estimated imperviousness for the subcatchment;

---

* API - Antecedent Precipitation Index

FIGURE I-5

ESTIMATION OF MAXIMUM INFILTRATION RATE
USED IN HORTON'S EQUATION FROM NUMBER OF
ANTECEDENT DRY DAYS



l_n is the percentage of particular land use (commercial, industrial, etc) found in that subcatchment (land use area/total area), and

i_n is the average percent imperviousness for that land use found in Table I-13.

It was determined for each subcatchment in the planning area for existing and future condition. These values were then used to determine the coefficient "a" for each pollutant to be modeled.

An estimate of the total runoff was made for each design storm by estimating the runoff from pervious and impervious areas in each subcatchment. Runoff from impervious areas was estimated by the following equation:

$$R_I = (P - S_{TI}) \times I(\%)$$

where: R_I is the total runoff in inches from all impervious areas in the subcatchment;

P is the total design rainfall volume in inches;

$I(\%)$ is as previously defined; and

S_{TI} is the surface storage on impervious areas and is assumed equal to 0.062 inches (33)

Runoff from pervious areas was estimated by the following equation:

$$R_P = (P - f_a) - S_{TP} * (1.0 - I(\%)$$

where: R_P is the runoff in inches from pervious areas;

P and $I(\%)$ are as previously defined; and

S_{TP} is the rainfall storage on pervious areas and is assumed equal to 0.184 inches; (33)

f_A is the sum of infiltration losses for a specific number of incremental time periods as computed using Horton's equation.

The total runoff volume for each design storm is therefore estimated as

$$X = R_I + R_P \text{ (in inches)}$$

TABLE I-13

ESTIMATE OF IMPERVIOUSNESS BY LAND-USE (27,43)

Land-Use		Percent Imperviousness (i_n(%))
1. Single Family Residential		25%
2. Multi-Family Residential		70%
3. Commercial		90%
4. Industrial		70%
5. Open		3%
a. Parks	12%	
b. Agriculture	4%	
c. Natural (Open)	2%	

To determine annual runoff volumes a statistical analyses was performed on runoff data from 12 USGS runoff gaging stations. The area upstream of each gage was evaluated as to area, imperviousness, predominant soil type, and average annual runoff in inches. (32, 39) Table I-14 presents a summary of the information.

The results of this analysis is a set of equations relating the imperviousness of subcatchment and annual runoff in inches for each soil type. These equations are given as:

Type I: Annual runoff = 11.25 + .287I (inches)

Type II: Annual runoff = 8.48 + .316I (inches)

Using this methodology to determine runoff volumes and the pollutant loading equation previously discussed total pollutant loads in pounds per acre and tons can be generated for each of the 292 subcatchments to be evaluated in this study.

For those segments which the SWMM is to be exercised to generate hydrographs and selected pollutographs these pollutant loads become P_o as discussed previously.

Water Quality Output Data

Peak concentrations of pollutants and peak flows as well as total quantities of both stormwater and pollutants for each major basin are shown as Appendix B. SWMM outputs, in the form of pollutographs and hydrographs for each source entering the main body of those streams mentioned on page I-2, have been delivered to the Texas Water Quality Board (TWQB) staff. This data will be utilized by the TWQB in a receiving water body stormwater response model named WRECEV and developed by Water Resources Engineers. This model will give receiving body water quality as a result of stormwater and pollutant inflows.

TABLE I-14

SUMMARY OF ANNUAL RUNOFF DATA (32m 39)

USGS GAGE	AREA (mi^2)	I(%)	S	AVERAGE ANNUAL RUNOFF (inches)
08071450	8.81	4.1	I	10.49
08074250	11.5	10.5	I	12.05
08074500	84.7	9.0	I	11.05
08075900	35.5	1.1	I	7.31
*	--	100.00		40.00
08074800	9.28	2.1	II	10.77
08075000	88.4	15.0	II	14.22
08075400	20.2	5.3	II	14.93
08075500	64.0	11.0	II	13.22
08075770	14.4	14.8	II	16.42
*	--	100.00		49.00

* estimate of annual runoff volume for area 100% impervious. Based on an annual mean rainfall of 44.44 inches and 10% lossed due to surface detention and evaporation.

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CHAPTER II - PRELIMINARY ASSESSMENT OF SEPTIC TANK IMPACTS

CHAPTER II - PRELIMINARY ASSESSMENT OF SEPTIC TANK IMPACTS

Summary

Based on theoretical calculations, the Sims Bayou Basin has the greatest pollutional impact from septic tanks. Greens Bayou Basin, with one-half of its area occupied by single family dwelling units utilizing septic tanks as a means of domestic waste treatment, has the second largest pollutant loadings from septic tanks. The theoretical analysis of the calculated loadings, with no calibrations to actual stream conditions results in loading values for Biochemical Oxygen Demand (BOD_5) and Fecal Coliforms that are very sensitive to, and directly proportional to, the size of the septic tank areas.

Introduction

Septic tanks have been used as a means of waste disposal for many decades. In recent years, it has become a less desirable method of waste treatment in densely populated areas for the following reasons:

1) A large land area is required for proper installation of the system,

2) The close proximity of housing as communities become large and do not allow enough area for the septic tank system, and

3) Decreased aesthetic value and possible health hazards are caused by malfunctioning units.

It is economically and aesthetically desirable to provide modern sewage collection and treatment facilities in communities that are densely populated. However, for modern rural homes and less densely populated rural communities, the septic tank system is still the accepted method of waste treatment.

Description of Septic Tank Systems

Components

A septic tank system for domestic waste disposal consists of two major components. The first component is the septic tank itself. Septic tanks are either circular or rectangular in shape, and are made of concrete or properly coated metal of water-tight construction. In general, septic tanks are made large enough to hold sewage from a home for about a two-day period. During this period, sewage solids will settle out and will be anaerobically decomposed. The effluent of the septic tank will be discharged into the drain field or a soil absorptive system, the second component of the septic tank disposal system.

The soil absorptive system or drain field usually consists of drain tiles or pipe in gravel trenches. Ideally, effluents from septic tanks are discharged into the drain field where liquids will seep into the ground at a slow rate without creating health hazards.

Site Considerations

In general, the proposed site for a septic tank and absorptive system must be located a safe distance from residences, water wells, and streams. In addition, the site should not be located in an area subject to flooding, and the topography of the area should permit gravity flow through a septic tank disposal system. Table II-1 shows some suggested minimum safe distances:

TABLE II-1

MINIMUM SAFE DISTANCES (IN FEET) FOR SEPTIC TANK SYSTEMS (1)

From To:	Septic Tank	Soil Absorptive System	Cast Iron Sewers	Vitrified Clay Pipe With Water-Tight Joints
Water Wells, Cisterns and Pump Suction Pipes	50	150	10	50
Streams and Ponds	75	75	--	75
Foundation Walls of Structures	5	15	--	--
Property Lines	10	10	--	--

Factors Affecting Soil Absorptive Systems

How satisfactorily the septic tank disposal system works depends largely on the rate at which septic tank effluent moves into the soil. Factors (2) that may affect the soil suitability are discussed in the following paragraphs.

Soil Permeability. The rate of water movement through the soil is called its permeability. Generally, soil permeability is influenced by the content of gravel, sand, silt and clay present in the soil. Water will pass through sandy and gravelly soil easier than clayey soil. The kind of clayey particles in soil is also important. For example, plastic clay, which will expand when wet, will swell and will not be able to absorb septic tank effluent.

Ground Water Level. Some soils have a groundwater level within a few feet of the surface year round. Some soils have a high groundwater level during only certain seasons. Other soils may have a high groundwater level during periods of prolonged rainfall. When the groundwater level rises to the same level as that of the drain tiles or pipes in the absorptive system, the effluent will rise to the surface of the ground, causing ill smelling and unhealthy bogs. In general, groundwater levels must be at least four feet below the ground surface.

Types of Underlying Materials. Impervious strata should be at least four feet below the bottom of the soil absorptive system. Septic-tank filter fields may fail if there is only a small layer of soil over the impervious strata.

Proximity of Ditches, Streams and Lakes. Filter fields should not be placed near open ditches, streams and lakes because high standing water impairs their effectiveness. Unfiltered and contaminated septic tank effluent may escape and spread into nearby water courses.

Design Considerations

In general, the available soil information does not provide percolation test results but gives the permeability of the soil. Permeability differs somewhat from percolation. Permeability is strictly downward movement of the water in the most restrictive soil layer whereas percolation is both downward and lateral movement in a particular depth. Percolation test results are used in the design of the absorptive field elements of septic tank disposal systems. Table II-2 shows some of the requirements based on percolation test results.

TABLE II-2

MINIMUM REQUIRED TRENCH PER BED ROOM (1)

Average Percolation Rate (Minutes Per Inch)	Required Trench Bottom Area (Square Feet)	Total Trench Length (Feet) for Specified Trench Widths 18"	24"	30"	36"
1	85	57	43	34	29
3	100	67	50	40	34
4	115	77	58	46	39
5	125	84	63	50	42
10	165	110	83	66	55
15	190	127	95	76	64
30	250	167	125	100	84
45	300	200	150	120	100
60	330	220	165	132	110
Over 60	Unsuitable for soil absorptive systems				

Notes: 1) A minimum-sized installation should be designed on the basis of a two bedroom house; i.e., double the minimum area requirement as given above.

2) This table provides for the normal household appliances, including automatic sequence washer, mechanical garbage grinder and dishwasher.

Maintenance of Septic Tanks

Maintenance of septic tanks is essential to their proper operation. They should be inspected yearly and should be cleaned before the volume of settled sewage solids becomes too great. If the accumulated solids layer or floating solids layer becomes too close to the outlet of the septic tank, solids may overflow and enter soil absorptive system. When this occurs, the absorptive capacity of the drain field will be reduced. Eventually, a new soil absorptive system will be necessary, because the old one will have become clogged.

To prevent this from occurring septic tanks should be professionally cleaned. Solids accumulated in the bottom layer of septic tanks should be removed. Septic tank contents should be treated with caution because they may contain disease-causing organisms. Disposal to a municipal treatment plant is recommended and is required in some areas.

Conditions In Planning Area

Exhibit No. II-1 shows the following information within the Greater Houston 208 Planning Area:

1) Flood Prone Areas

Information on flood prone areas was based on data prepared by the U. S. Geological Survey, the Federal Insurance Administration and the U. S. Amry Corps of Engineers.

2) Septic Tank Areas

Information on the septic tank areas was based on data from the City of Houston Health Department and the Houston-Galveston Area Council.

3) Soil Conditions with Severe Limitation for Septic Tank Usage

Information on soil conditions with severe limitations for septic tank drain fields was based on the surveys available through the U. S. Department of Agriculture Soil Conservation Services for Harris, Montgomery, Galveston, Brazoria, and Waller Counties.

Soil Limitations

The majority of soil in the Greater Houston 208 Planning Area has severe limitations for septic tank drain field operations. With the prolonged rainfall, high groundwater tables, and poor drainage inherent to the entire Greater Houston 208 Planning Area, the operation of septic tanks is a limited waste disposal method.

From Exhibit No. II-1, it can be seen that in the northern portion of the Greater Houston 208 Planning Area, the soil limitations are moderate, allowing septic tank systems to be used if the systems are properly maintained; however, the southern portion of the Planning Area has severe soil limitations.

Septic Tank Systems in Flood Prone Areas

Those areas presently utilizing septic tank systems which are located within the flood prone areas will further encounter severe operational problems. Frequent flooding of the drain field reduces its effectiveness, forcing the unfiltered sewage to the surface of the ground, and allowing it to enter surface water.

Ultimate Disposal of Septic Tank Sludge

A telephone survey of approximately fifteen professional septic tank cleaning firms servicing the Greater Houston 208 Planning Area showed that these trucks discharge septic tank sludge solids into several municipal sewage treatment facilities.

Septic Tank Pollutant Loadings

Pollutant loadings from septic tanks have been determined in a similar manner as that of sediment yield from storm runoff. The two parameters which will be used as indicators of septic tank pollutional impacts are Biochemical Oxygen Demand (BOD_5) and Fecal Coliforms. Septic tank pollutional impacts are influenced by several design and operational problems mentioned earlier in this Chapter. The more serious problems are:

1) Effluents from septic tanks discharging directly into roadside ditches and streams without first going through the soil absorptive systems; and

2) Malfunctioning soil absorptive systems, in which case effluents from septic tanks enter soil absorptive fields and immediately surface on the top of the soil. This wastewater may flow into roadside ditches and streams or may remain stagnant and become septic.

Not all septic tank effluents from direct discharging systems or malfunctioning soil absorptive systems are transported out of the watershed. The quantity that is transported may be estimated utilizing the relationship between gross concentration from septic tank areas and the delivery ratio, in much the same manner as sediment yield is determined based on gross soil erosion and a sediment delivery ratio according to the following expression:(4)

Sediment yield = K x gross soil erosion

Where: K = Sediment delivery ratio

Sample Calculations

A septic tank area, located in Spring Creek Basin and Subcatchment No. 3, has an area of 683 acres in 1975. This area is located approximately 5.6 miles from the node of the Subcatchment No. 3. The soil in the subcatchment is sandy clay. The determination of Biochemical Oxygen Demand (BOD_5) and fecal coliform loadings are described in the following paragraphs.

Biochemical Oxygen Demand (BOD_5) Loading.

1) BOD_5 Loading Per Acre

In accordance with Design Criteria for Sewerage Systems (5), the daily BOD_5 loading of 0.17 lbs. per person will be used in the residential areas. It is also assumed that there is an average of four single family dwelling units per acre, and 3.5 persons per single family dwelling unit. Therefore, the daily BOD_5 loading per acre will be 3.5 x 4.0 x 0.17 = 2.38 lbs. per acre per day.

2) Sewage Flow Per Acre

A sewage flow contribution of 100 gallons per person per day will be used; therefore, the sewage flow contribution per acre will be 3.5 x 4 x 100 = 1,400 gallons per acre per day.

3) Percent BOD_5 Reduction in a Septic Tank

Very little BOD reduction is expected in a septic tank because of the anaerobic nature and the short detention time. Hickey and Duncan (6) observed 25 to 50 percent reductions in BOD_5 in their work. A 50 percent reduction of BOD_5 is assumed in these calculations.

4) Percent Malfunctioning Septic Tank Soil Absorptive Field Systems

The most common septic tank installations use soil absorptive fields as a part of the treatment process. However, older installations without soil absorptive fields have been known to exist. Effluents from these installations are discharged directly into roadside ditches and streams. Polkowski and Boyle (7) indicated that the useful life for septic tank soil absorptive systems is 15 to 20 years, if the systems are properly installed at an acceptable location in suitable soil and properly maintained. In some post World War II U. S. communities, McGauhey and Winneberger (8) observed that one-third of the installation failed to operate properly within 3 to 4 years after installation.

In these calculations, it is assumed that 30 percent of the septic tank soil absorptive systems are malfunctioning based on the study by McGauhey and Winneberger (8). The actual percentage of malfunctioning septic tank systems for each subcatchment area can be better determined if field observations were made.

Therefore, the flow per acre, which will enter roadside ditches and streams and will cause pollutional problems, is calculated as follows:

Sewage flow per acre per day x percent septic tank system malfunctioning

= 1,400 gallons per acre per day x 0.30
= 420 gallons per acre per day

A further assumption that is made in this assessment is that the remaining portion of the sewage flow which enters the soil through the soil absorptive system has no pollutional impact.

BOD_5 loading due to malfunctioning septic tank systems can be calculated as follows:

BOD_5 contribution per acre per day x percent reduction of BOD_5 in septic tank soil absorptive system x percent malfunctioned septic tank systems

= 2.38 lbs per acre per day x 0.50 x 0.30
= 0.36 lbs per acre per day

5) Determination of Delivery Ratio

After effluents from malfunctioning septic tank systems reach the soil surface, these effluents may enter roadside ditches or remain over the soil absorptive areas. These effluents may reach the node of each subcatchment area by flowing along roadside ditches to a major stream. The BOD_5 loading at the node of each subcatchment area will be determined based on the delivery ratio. The percent of septic tank effluent carried off of a drainage area can be determined from Figure II-1.

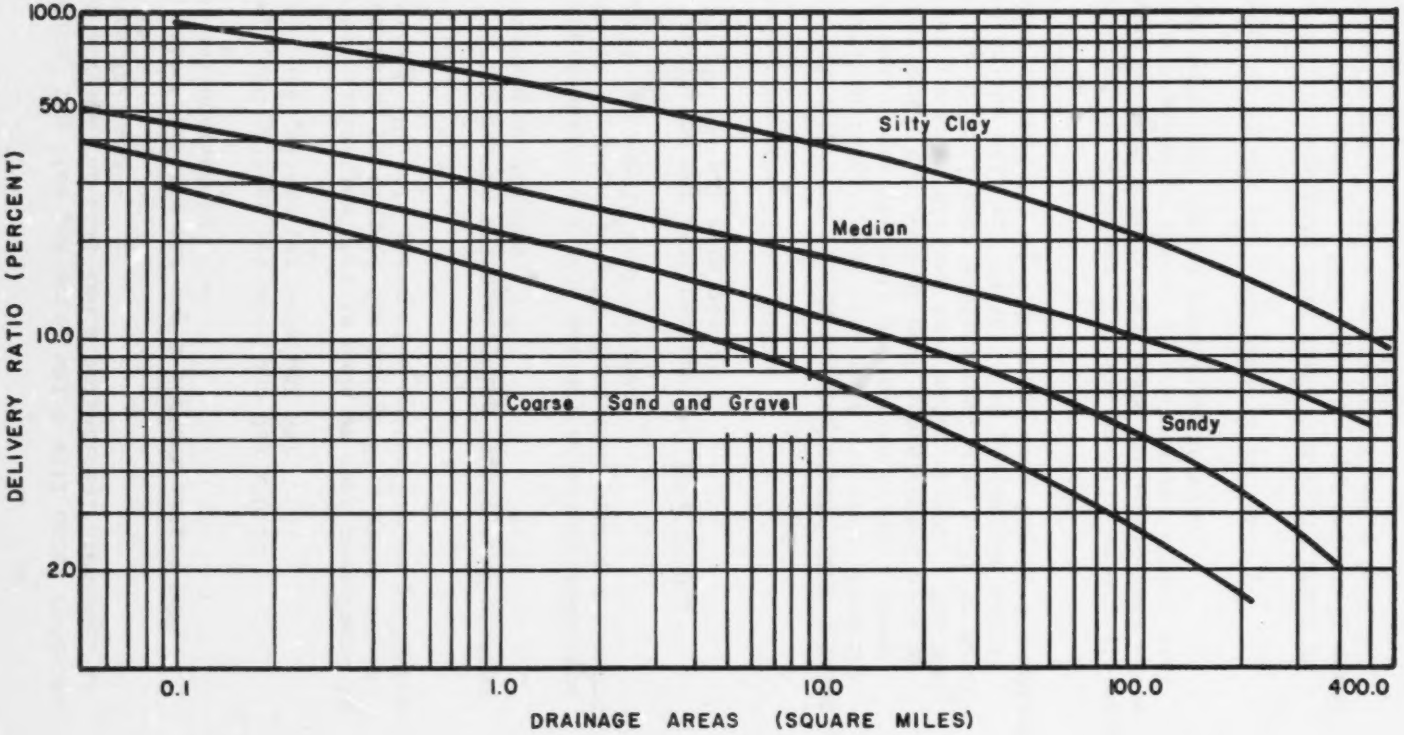
A modification of Figure II-1 was made to relate distances from the node of each subcatchment area to septic tank areas within each subcatchment since, in most cases, septic tank areas do not cover the entire subcatchment area.

A replot of Figure II-1 was made as follows:

An assumption was made that runoff velocity would be 0.5 feet per second. This value is approximately equal to the velocity of the storm runoff flowing over a grassy terrain.

FIGURE II-1

SEPTIC TANK EFFLUENT DELIVERY RATIO VS. SIZE OF DRAINAGE



A distance from the center of each area can be determined with an assumption that each area in Figure II-1 is to be a square.

A plot of delivery ratios vs. time, based on the preceding two paragraphs, is presented in Figure II-2. It should be pointed out that Figure II-1 was prepared by the Soil Conservation Service for the general area. To be more precise, a plot of delivery ratio vs. time should be experimentally prepared for each subcatchment.

To obtain the delivery ratio, first calculate the travel time from septic tank areas to the node of each subcatchment by dividing the distance by an assumed runoff velocity of 0.5 feet per second. One can therefore determine a delivery ratio (K) from Figure II-2 from the calculated travel time.

If there were to be more than one septic tank area in one subcatchment, an average travel time is used to determine a delivery ratio.

For a septic tank area in Spring Creek Basin and Subcatchment No. 3:

$$\text{Travel time} = \frac{\text{5.6 miles}}{\text{0.5 feet per second}}$$

$$= \text{16.43 hours}$$

A delivery ratio for sandy soil is determined to be 4.0 from Figure II-2.

6) Final Calculation

The BOD_5 loading from the septic tank area in Spring Creek Basin Subcatchment No. 3 will be equal to:

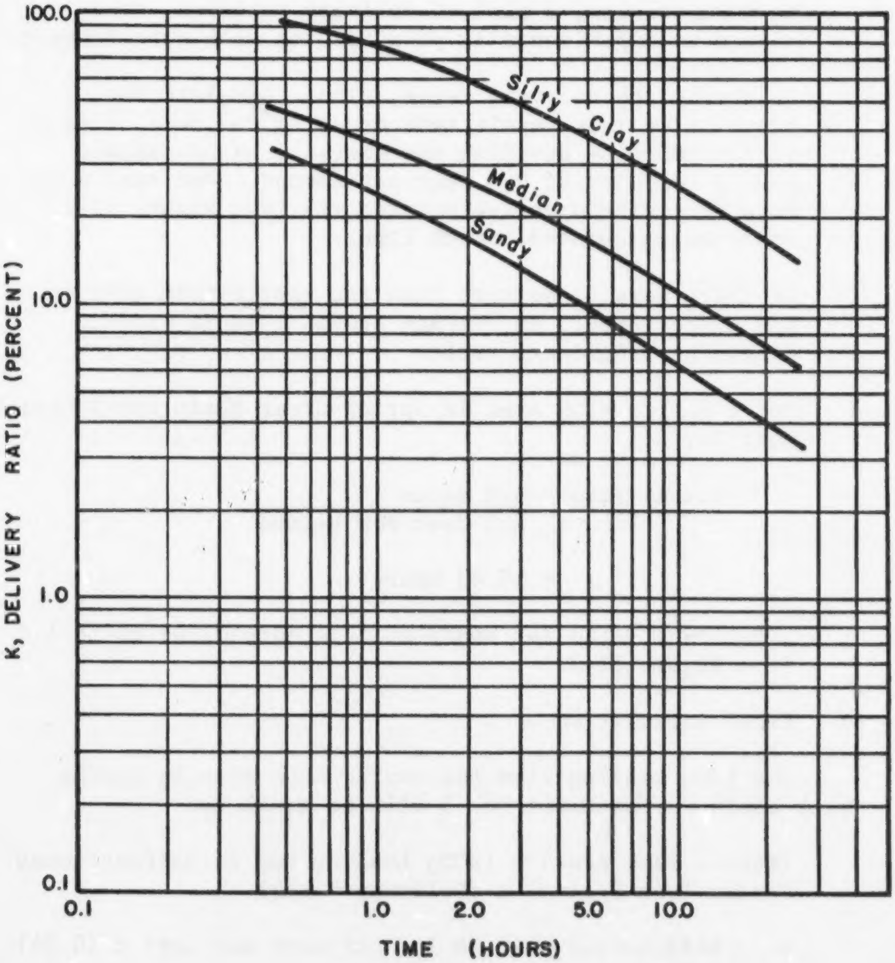
(Septic Tank Area) x (BOD_5 Loading due to Malfunctioned Septic Tank System) x (Delivery Ratio)

= (683 acres) x (0.36 lbs per acre per day) x (0.04)
= 9.84 lbs per day

Fecal Coliform Loading. Septic tanks cannot be relied upon as a system used to remove significant amounts of fecal coliforms or dissolved organic materials. The septic tank itself serves only to partially separate settleable solids from sewage. These

FIGURE II - 2

DELIVERY RATIO VS. TRAVEL TIME



settleable solids then are further broken down by anaerobic bacterial action in the bottom of the tank.

The liquid portion of the sewage enters the soil absorptive system. Fecal coliforms in solution are removed through the soil absorptive system either by filtering or straining actions and/or bacterial die-off action.

Since there are limited studies concerning bacterial removal through soil absorptive systems, an example of bacterial removal by filtering through sand filters will be cited as a comparison.

An empirical relationship between the bacterial effluent concentration and the bacterial influent concentration in water has been established as follows: (9)

$$E = cR^n$$

where:
E = bacterial effluent concentration
R = bacterial influent concentration
c = coefficients reflecting the effluent concentration of coliform organisms for a given raw water concentration
n = the relative shift in effluent concentration with changing raw water concentration

Observed values (9) for c and n and the MPN per 100 ml in the influent to produce an effluent concentration of 1 MPN per 100 ml are:

$c = 70 \times 10^3$
$n = 0.60$
R = 80 MPN per 100 ml

Reported values for coliform bacterial concentration in septic tank effluents vary from 5×10^6 MPN per 100 ml to 93×10^6 MPN per 100 ml as shown in Table II-3. (11) A recent study (10) on bacterial characteristics of stormwaters in developing rural areas shows that the MPN per 100 ml for fecal coliforms in septic tank influents to be 30×10^6, which is the concentration assumed for the influent of the septic tank.

Based on the information on reduction of coliform bacteria through straining action and bacterial die-off action, an assumption is made that 99.9 percent of fecal coliforms can be removed in a septic tank soil absorptive field system; therefore, the remainder of fecal coliforms in the septic tank drain field discharge are:

TABLE II-3

AVERAGE COMPOSITION OF SEPTIC TANK EFFLUENT (11)

Parameter	Preul (1965)	Robeck, et al. (1964)	Polkowski & Boyle (1970)
Total Susp. Solids, mg/l	40	46	74
Vol. Susp. Solids, mg/l	---	36	60
BOD_5, mg/l	130	90	102
Dissolved Oxygen, mg/l	0	---	---
pH	7.0-7.5	7.5-8.1	---
Alkalinity, mg/l	300	400	--
Organic Nitrogen, mg/l	10	5.4	16.2
NO_2-N, mg/l	0.003	0.008	.065
NO_3-N, mg/l	0.15	0.11	0.13
NH_3-N, mg/l	25	22	14.0
Total Phosphates, mg/l	20	---	---
K, mg/l	10-15	---	---
Na, mg/l	100	---	---
Sulphates, mg/l	50	---	---
Chlorides, mg/l	70	75	43.0
Coliform Bacteria/100 ml	---	5 million	93 million

$(1.000 - 0.999) \times 30 \times 10^6 = 30 \times 10^3$ MPN/100 ml

Change to MPN/gallon =
30×10^3 MPN/100 ml x 1,000 ml/l x 3.78 l/gallon =
11.34×10^5 MPN/gallon

Fecal Coliform loading per acre =

11.34×10^5 MPN/gallon x 420 gallon/acre/day =
47.63×10^7 MPN/acre/day

To obtain fecal coliforms loading at the node of each subcatchment, the following calculations are made:

(Fecal Coliform Loading per acre per day) x (Septic Tank area) x (Delivery Ratio)
or for Subcatchment No. 3 of Spring Creek Basin in 1975, the loading is:

47.63×10^7 MPN/acre/day x 683 acres x 0.046 =
15.0×10^9 MPN/day

Calculation procedures to determine BOD_5 loading and fecal coliforms loading for Spring Creek Basin are shown in Table II-4.

Septic tank areas for the years 1983, 1990, and 1995 were estimated based on the land use population projection for single family areas for that particular year. In Subcatchment No. 3 of Spring Creek Basin (Table II-4), the single family area and the septic tank area in 1975 are the same, but in other subcatchments these areas may not be the same. Since there is no method, other than field inspections, to determine the percentage of septic tank areas from the increased projected single family areas, it is assumed that all of the projected increased single family areas will be on septic tank soil absorptive systems. In cases where the projected single family areas decrease, the largest number of the septic tank areas will be used to obtain a maximum pollutional loading for that particular subcatchment.

Based on the presented methodology, septic tank pollutional impact loadings for the Greater Houston 208 Planning Area are presented in Table II-5 for each basin and each subcatchment area.

TABLE II-4

SAMPLE CALCULATIONS BOD_5 AND FECAL COLIFORMS LO

SUBCATCHMENT NO.	SUBCATCHMENT AREA (ACRES)	DISTANCE FROM SEPTIC TANK AREA TO NODE (MILES)	TRAVEL TIME (HOURS)	BOD_5 CONTRIBUTION (LBS/ACRE/DAY)	% BOD_5 REDUCTION IN SEPTIC TANK SOIL ABSORPTIVE SYSTEM	% SEPTIC TANK SOIL ABSORPTIVE SYSTEM MALFUNCTION	BOD_5 LOADING AFTER SEPTIC TANK SOIL ABSORPTIVE SYSTEM (LBS/ACRE/DAY)
1	2	3	4	5	6	7	8 = 5x6x7
1	31,533						
2	28,832						
3	49,971	5.6	16.41	2.38	50	30	0.36
4	46,848	6.7	19.63	2.38	50	30	0.36
5	11,366						
6	6,323						
7	7,040						
8	8,320	4.1	12.01	2.38	50	30	0.36
9	7,782						
10	9,754						
11	6,349						
12	9,114						
13	34,637	3.5	10.26	2.38	50	30	0.36
14	3,635						
15	20,250	7.6	22.27	2.38	50	30	0.36
TOTAL	281,754						

1990				1995					
SINGLE FAMILY AREA (ACRES)	CHANGE IN SINGLE FAMILY AREA	SEPTIC TANK AREA (ACRES)	TOTAL BOD_5 LOADING (LBS/DAY)	SINGLE FAMILY AREA (ACRES)	CHANGE IN SINGLE FAMILY AREA	SEPTIC TANK AREA (ACRES)	TOTAL BOD_5 LOADING (LBS/DAY)	FECAL COLIFORM IN SEPTIC TANK INFLUENT (10^6MPN/100ML)	% REDUC FECAL CO SEP TANK ABSORP SYST
17	18 = 17-13	19 = 15+18	20 = 19x8x11	21	22 = 21-17	23 = 22+19	24 = 23x8x11	25	26
1,024				1,220					
596				598					
937	+ 122	952	15.77	1,050	+ 113	1,065	17.64	30	99
1,778	+ 91	1,778	25.60	1,869	+ 91	1,869	26.94	30	99
336				360					
687				763					
434				419					
550	- 23	198	3.85	536	- 14	198	3.85	30	99
419				470					
125				132					
871				924					
1,035				1,189					
1,129	- 59	486	10.50	1,082	- 47	486	10.50	30	[illegible]
236				258					
1,670	+ 344	1,292	17.67	1,909	+ 239	1,531	20.94	30	99
			73.39				79.84		

A

TABLE II-4

OD$_5$ AND FECAL COLIFORMS LOADINGS FOR SPRING CREEK BASIN

		1975				1983			
% SEPTIC TANK SOIL ABSORPTIVE SYSTEM MALFUNCTION	BOD$_5$ LOADING AFTER SEPTIC TANK SOIL ABSORPTIVE SYSTEM (LBS/ACRE/DAY)	SINGLE FAMILY AREA (ACRES)	SEPTIC TANK AREA (ACRES)	DELIVERY RATIO % (K)	TOTAL BOD$_5$ LOADING (LBS/DAY)	SINGLE FAMILY AREA (ACRES)	CHANGE IN SINGLE FAMILY AREA	SEPTIC TANK AREA (ACRES)	TOTAL BOD$_5$ LOADING (LBS/DAY)
7	8 = 5x6x7	9	10	11	12 = 8x10x11	13	14 = 13-9	15 = 10+14	16 = 15x8x11
		502				772			
		627				606			
30	0.36	683	683	4.6	11.31	815	+ 132	815	13.50
30	0.36	1,560	1,560	4.0	22.46	1,687	+ 127	1,687	24.29
		264				306			
		445				587			
		445				453			
30	0.36	574	198	5.4	3.85	573	- 1	198	3.85
		228				338			
		85				109			
		48				813			
		560				811			
30	0.36	1,144	442	6.0	9.55	1,188	+ 44	486	10.50
		144				207			
30	0.36	896	518	3.8	7.09	1,326	+ 430	948	12.97
					54.26				65.11

					FECAL COLIFORMS REACH NODE OF SUBCATCHMENT (10^9MPN/DAY)			
TOTAL BOD$_5$ LOADING (LBS/DAY)	FECAL COLIFORM IN SEPTIC TANK INFLUENT (10^6MPN/100ML)	% REDUCTION FECAL COLIFORM SEPTIC TANK SOIL ABSORPTIVE SYSTEM	FECAL COLIFORM IN EFFLUENT OF SOIL ABSORPTIVE FIELD (10^3MPN/100ML)	FECAL COLIFORMS LOADING (10^7MPN/ACRE/DAY)	1975	1983	1990	1995
24 = 23x8x11	25	26	27	28	29 = 10x11x28	30 = 15x11x28	31 = 19x11x28	32 = 23x11x28
17.64	30	99.9	30	47.63	15.0	17.9	20.9	23.3
26.94	30	99.9	30	47.63	29.7	32.1	33.9	35.6
3.85	30	99.9	30	47.63	5.1	5.1	5.1	5.1
10.50	30	99.9	30	47.63	12.6	13.9	13.9	13.9
20.94	30	99.9	30	47.63	9.4	17.2	23.4	27.7
79.84					71.8	86.2	97.2	105.6

B

TABLE II-5

SEPTIC TANK POLLUTIONAL IMPACT LOADINGS

NAME OF BASIN	Subcatchment No.	1975		1983		1990		1995	
		BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)
01 Addicks	2	11.5	15.2	11.5	15.2	11.5	15.2	11.5	15.2
		11.5	15.2	11.5	15.2	11.5	15.2	11.5	15.2
05 Brays	2	11.5	15.2	12.2	16.2	12.2	16.2	12.2	16.2
	12	12.4	16.7	15.2	20.6	17.2	23.3	19.1	25.9
	13	8.1	10.7	20.8	26.7	34.4	44.2	46.8	60.0
	21	32.0	42.3	49.6	64.9	61.2	80.2	69.2	90.5
	24	25.6	33.8	40.8	54.3	47.9	63.6	53.0	70.4
	25	61.5	81.4	75.3	99.6	81.2	107.4	84.8	112.2
	26	21.1	27.9	34.4	46.4	43.9	59.3	50.6	68.3
	30	67.5	90.1	71.6	94.2	71.6	94.2	71.6	94.2
	36	21.6	27.7	21.6	27.7	21.6	27.7	21.6	27.7
	37	36.5	48.3	40.6	52.5	43.7	56.5	46.5	60.1
		297.8	394.1	382.1	503.1	434.9	572.6	475.4	625.5
06 Buffalo	11	13.4	17.7	15.5	21.0	16.0	21.7	16.4	22.3
	26	43.7	57.9	43.7	57.9	43.7	57.9	43.7	57.9
		57.1	75.6	59.2	78.9	59.7	79.6	60.1	80.2
07 Carpenter	8	18.7	24.7	48.9	69.9	63.6	90.9	73.9	105.6
		18.7	24.7	48.9	69.9	63.6	90.9	73.9	105.6
08 Cedar	1	3.3	4.4	3.5	4.7	3.5	4.7	3.5	4.7
	3	6.6	8.7	26.1	34.2	32.7	42.9	38.4	50.3
	4	47.4	62.7	97.5	121.9	106.3	132.9	109.9	137.4
		57.3	75.8	127.1	160.8	142.5	180.5	151.8	192.4
09 Clear Creek	2	118.0	156.0	172.0	226.7	240.0	316.0	319.4	421.3
	3	43.0	56.9	50.3	63.9	55.5	70.5	60.2	76.4
	6	90.8	120.1	108.5	155.1	136.3	194.8	163.7	234.0
		251.8	333.0	330.8	445.7	431.8	581.3	543.3	731.7

TABLE II-5

SEPTIC TANK POLLUTIONAL IMPACT LOADINGS
(Continued)

NAME OF BASIN	Subcatchment No.	1975		1983		1990		1995	
		BOD$_5$ (lbs/day)	Fecal Coliform (10^9 MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9 MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9 MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9 MPN/day)
11 Cypress	6	3.1	4.1	3.2	4.1	3.2	4.1	3.2	4.1
	8	41.4	54.8	255.9	346.5	457.7	619.6	615.2	832.8
	9	23.8	31.4	23.8	31.4	23.8	31.4	23.8	31.4
	10	76.0	100.5	76.0	100.5	76.0	100.5	76.0	100.5
	11	26.4	34.9	27.2	35.7	27.2	35.7	27.2	35.7
	12	49.3	65.2	50.4	65.2	50.4	65.2	50.4	65.2
	13	160.1	211.8	192.6	249.1	192.6	249.1	192.6	249.1
	16	36.2	47.9	127.2	161.6	166.6	211.6	196.3	249.4
	17	40.8	54.0	68.5	89.0	75.9	98.6	80.8	105.0
	18	62.4	82.5	105.7	132.1	107.5	134.4	107.5	134.4
		519.5	687.1	930.5	1,215.2	1,180.9	1,550.2	1,373.0	1,807.6
12 Dickinson	2	140.1	185.4	153.2	200.7	161.9	212.1	170.9	223.8
		140.1	185.4	153.2	200.7	161.9	212.1	170.9	223.8
13 Goose Creek	2	28.1	37.2	42.4	57.6	43.3	58.9	43.5	59.2
		28.1	37.2	42.4	57.6	43.3	58.9	43.5	59.2
14 Greens	1	56.7	75.0	81.0	102.9	89.4	113.6	95.5	121.3
	2	14.7	19.5	31.7	41.5	41.8	54.8	50.1	65.6
	4	109.6	145.0	138.4	184.6	156.5	208.7	171.2	228.3
	5	178.4	236.1	254.2	322.8	284.3	361.1	306.6	389.4
	6	14.3	18.9	60.5	81.2	78.5	105.4	92.6	124.3
	7	83.1	109.9	124.2	162.7	163.4	214.1	196.9	257.9
	9	43.3	57.4	64.1	87.3	67.6	92.4	70.1	95.4
	11	89.6	118.5	127.3	166.7	149.8	196.3	167.7	219.6
	12	146.4	193.7	200.4	270.4	243.7	328.9	286.2	386.2
	13	100.9	132.1	117.6	154.0	120.3	157.6	121.4	159.1
	15	24.9	32.9	38.3	50.2	41.0	53.8	42.6	55.9
		861.9	1,139.0	1,237.7	1,624.3	1,436.3	1,886.7	1,600.9	2,103.0

TABLE II-5

SEPTIC TANK POLLUTIONAL IMPACT LOADINGS
(Continued)

NAME OF BASIN	Subcatchment No.	1975		1983		1990		1995	
		BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)
15 **Hunting**	2	16.6	21.9	16.6	21.9	21.4	29.2	26.9	36.6
	5	107.0	141.6	107.0	141.6	107.0	141.6	107.0	141.6
	6	67.0	88.6	74.2	98.1	86.6	114.6	99.4	131.5
	7	38.3	50.7	62.0	84.4	94.2	128.2	127.1	173.0
	8	14.0	18.6	22.5	29.8	31.3	41.4	38.5	51.0
	9	59.4	78.6	75.4	97.9	85.9	111.6	92.4	120.0
	10	42.1	55.7	46.6	60.6	49.9	64.8	52.4	68.0
	12	299.1	395.8	299.1	395.8	299.1	395.8	299.1	395.8
		643.5	851.5	703.4	930.1	775.4	1,027.2	842.8	1,117.5
16 **Lower San Jacinto**	1	10.5	13.9	13.3	17.6	14.0	18.6	14.6	19.3
	4	31.5	42.9	39.8	54.1	43.5	59.3	46.5	63.2
	5	69.9	92.5	92.2	120.7	102.6	134.4	109.2	143.0
	6	57.5	76.1	72.5	92.1	77.4	98.3	77.4	98.3
	7	20.2	26.7	20.2	26.7	20.2	26.7	20.2	26.7
		189.6	252.1	238.0	311.2	257.7	337.3	267.9	350.5
17 **San Jacinto**	1	32.1	42.5	39.2	56.0	42.7	61.0	45.2	64.6
	2	23.0	30.5	32.2	42.6	32.8	43.3	32.8	43.3
	3	64.5	87.8	80.8	109.9	81.5	110.9	82.3	112.0
		119.6	160.8	152.2	208.5	157.0	215.2	160.3	219.5
18 **Sims**	2	33.8	44.8	60.8	80.5	95.0	125.7	127.3	168.4
	3	36.7	48.4	36.7	48.4	36.7	48.4	36.7	48.4
	4	146.4	196.1	245.4	328.8	359.0	481.0	445.8	597.1
	5	96.0	128.0	111.9	149.2	125.0	167.0	135.8	181.0
	6	18.4	24.2	74.1	94.7	137.7	181.3	188.0	247.6
	7	83.2	111.5	102.7	137.6	126.6	169.5	150.7	201.9
	8	60.8	79.7	77.2	101.1	96.5	126.4	115.4	151.2
	9	8.9	11.9	10.6	14.1	12.5	16.7	14.2	18.9
	12	93.5	122.4	93.5	122.4	93.5	122.4	93.5	123.7
	13	102.8	135.4	129.2	170.1	135.7	178.6	135.7	178.6
	15	54.1	69.4	66.4	85.2	84.5	108.4	109.7	140.7
	16	91.3	119.1	104.4	136.2	122.6	159.9	138.7	180.9
	17	23.1	29.3	27.4	37.3	36.4	49.5	37.9	51.6
	18	86.8	112.2	99.7	135.6	115.6	149.5	133.8	173.0
	24	186.4	244.2	212.3	278.1	231.5	303.2	243.8	319.3
	25	25.9	33.8	25.9	33.8	25.9	33.8	25.9	33.8
	34	26.0	33.9	36.6	47.7	46.9	61.2	55.2	72.0
		1,174.1	1,544.3	1,514.8	2,000.8	1,881.6	2,482.5	2,188.1	2,888.1

TABLE II-5

SEPTIC TANK POLLUTIONAL IMPACT LOADINGS
(Continued)

NAME OF BASIN	Subcatchment No.	1975		1983		1990		1995	
		BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)	BOD$_5$ (lbs/day)	Fecal Coliform (10^9MPN/day)
19 Spring	3	11.3	15.0	13.5	17.9	15.8	20.9	17.6	23.3
	4	22.5	29.7	24.3	32.1	25.6	33.9	26.9	35.6
	8	3.9	5.1	3.9	5.1	3.9	5.1	3.9	5.1
	13	9.6	12.6	10.5	13.9	10.5	13.9	10.5	13.9
	15	7.1	9.4	13.0	17.2	17.7	23.4	20.9	27.7
		54.4	71.8	65.2	86.2	73.5	97.2	79.8	105.6
20 Upper Armand	8	22.3	29.6	32.5	43.8	39.1	52.8	48.1	64.9
	9	63.1	83.4	82.7	106.9	94.4	122.0	103.2	133.4
		85.4	113.0	115.2	150.7	133.5	174.8	151.3	198.3
21 Upper San Jacinto	2	43.6	57.6	65.4	85.6	70.0	91.7	72.8	95.4
	7	23.4	30.9	27.3	35.7	27.3	35.7	27.3	35.7
	8	10.3	13.7	13.6	17.8	15.9	20.7	17.6	22.9
	9	22.9	30.3	24.5	32.9	24.5	32.9	24.5	32.9
	10	9.7	12.8	59.4	79.2	71.4	95.2	77.4	103.2
	12	21.8	28.8	31.1	41.2	38.2	50.5	44.1	58.4
		131.7	174.1	221.3	292.4	247.3	326.7	263.7	348.5
22 White Oaks	1	122.2	161.6	129.6	167.5	129.6	167.5	129.6	167.5
	2	2.4	3.2	18.4	25.3	20.3	28.0	21.2	29.1
	4	119.6	158.3	157.6	217.7	191.4	264.4	221.7	306.2
	5	31.1	41.2	72.2	95.5	113.4	150.0	153.2	202.7
	6	62.0	82.1	97.9	82.1	127.6	167.1	152.1	199.2
	7	128.4	169.9	154.4	204.2	178.6	236.2	200.2	264.9
		465.7	616.3	630.1	792.3	760.9	1,013.2	878.0	1,169.6

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CHAPTER III - PRELIMINARY ASSESSMENT OF AGRICULTURAL, INJECTION WELLS, SHIPPING, OIL FIELD WASTE DISPOSAL, AND SALT WATER INTRUSION IMPACT

Preliminary Assessment of Oil Field Waste Disposal Impact

Summary

The oil field waste disposal practices in the Greater Houston 208 Planning Area were reviewed for the purpose of assessing impact upon surface and groundwater quality. The most significant contaminant for possible pollution to groundwater supplies is the brine produced during oil production operations. Brine disposal is either through tidal disposal or injection wells. In tidal disposal, the brine first undergoes separation of the salt water and the free oil before the brine is released to the bays. At the present time, no tidal disposal of brine is in operation in Harris County. Injection wells are therefore the only practical, legal means of disposal in the Planning Area because discharging brine directly into streams and brine disposal pits are against regulations as set by the Railroad Commission of Texas. The brine is pumped through injection wells either back into the same formation from which it came or into a formation with high chloride concentration. No aquifers containing potable groundwater were found to be employed as receiving aquifers. However, cases were reported that abandoned brine disposal pits may be affecting shallow potable water formations due to leakage and past misuse.

Another possible source for contamination to water supplies is solid waste that may be produced during drilling operations. Drilling mud makes up the majority of this solid waste. No studies were found that showed the quantity wasted or the relative impact upon stream quality; therefore, no assessment could be made.

Introduction

Oil production in the Greater Houston 208 Planning Area is very prevalent and has been a dominant force in the economy of the area. Harris County alone produced over thirty-two million barrels of crude oil in 1975, (1) twelth in Texas county standing. Major oilfields in the area can be seen in Exhibit III-1.

Assessment of the impact of hydrocarbon production upon water quality can be divided into four (4) major categories:

1) Brine disposal by well injection

2) Brine disposal into tidal waters

3) Oil spills

4) Solid waste disposal

On a daily operating basis, salt water from hydrocarbon production constitutes the only significant threat to the ground or surface water quality. Oil spills, though extremely damaging to the immediate water quality, are accidental in occurrence and therefore are controllable by enforcement of existing regulations on prevention and safety standards.

Brine Disposal Through Subsurface Injection

Introduction. Wells for the disposal of oilfield brine or waterflooding are used extensively in the oil industry and are regulated by the Railroad Commission of Texas. Each well must meet the requirements set by the Commission before a permit is granted and the well used for brine injection. Table III-1 lists the brine disposal wells by county in the Greater Houston 208 Planning Area.

Selection. Brine injection may be for formation pressure maintenance, water flooding or disposal. In pressure maintenance and waterflooding the producing formation is the chosen zone of injection. Selection of the zone of injection for produced brine disposal is more complex. Disposal zone choice should be based upon various factors: 1) geological, 2) hydrological, 3) geochemical, and 4) chemical. The disposal zone must have enough void volume to store the brine over the project life. The zone should not be over-pressured. The mineral composition of the disposal formation should be conducive to brine injection. The injected brine and the disposal zone brine must be chemically compatible at formation conditions.

Installation. An injection well installation may be made by converting an existing oil well or drilling and completing a new well. The configuration of a typical injection well is shown in Figure III-1 and its construction must meet criteria established by the Railroad Commission of Texas. Injection well construction includes setting of surface casing, protection casing, injection tubing and packer to a suitable formation approved by the Railroad Commission of Texas and the Texas Water Quality Board. The wells are constructed and maintained to prevent contamination of any fresh water aquifers by salt water which has leaked from the zone of disposal. The cement sheaths around the surface casing

TABLE III-1

BRINE DISPOSAL WELLS (5)

GALVESTON

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Cologne Prod. Company	Algoa	5/18/72	3190-3480	1100
Superior Oil Company	Algoa	2/05/74	3380-3885	1100
Superior Oil Company	Algoa	4/23/56	1800-2750	900
Texaco	Algoa, Orchard	4/02/64	2320-2850	850
Texaco	Algoa, Orchard	10/19/72	4800-6525	1100
Hassie Hunt Trust	Franks Field	12/13/68	1800-1850	*
Hassie Hunt Trust	Franks Field	2/24/69	1800-1850	1000
Placid Oil Company	Franks Field	4/15/63	4230-4255	*
Amoco	Gillock	5/08/68	2800-7410	1050
Amoco Prod. Company	Gillock, E.	2/24/76	3700-6800	<1500
Amoco Prod. Company	Gillock, E.	10/03/76	3700-6800	<1500
Atlantic Richfield Co.	Gillock, E.	1/27/76	3500-6450	1100
ARCO	Gillock, E.	8/07/72	3500-6480	*
Conoco	Gillock, E.	--	4750-5300	1150
Hassie Hunt Trust	Gillock, E.	11/24/75	2014-2150	1000

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

GALVESTON (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Superior Oil Company	Gillock, E.	9/17/71	2090-2560	*
Union Oil Co. of California	Gillock, E.	1/20/76	2000-6200	1200
Amoco Prod. Company	Hasting	9/27/71	2000-5200	*
Amoco	Hasting	9/27/71	1800-5300	*
Amoco	Hasting	9/27/71	2000-5160	*
Crown Central	Hasting	1/07/75	3650-4650	1200
Gulf Coast	League City	8/05/54	1700-1750	600
Midstate	League City	3/15/54	2080-2220	1600
Phillips	League City	12/21/54	1800-2400	1600
Phillips	League City	4/02/62	1882-2110	1600
Phillips	League City	10/18/54	2560-3030	1600
Phillips	League City	5/15/51	2150-2210	1600
Salt Dome Prop. Company	League City	6/07/54	2823-2883	1000
Superior Oil Company	League City	8/07/72	1800-2850	1250
Exxon	Webster	7/19/74	5986-6010	*

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

WALLER

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Amoco	Katy	3/03/47	4640-4680	*
ARCO	Katy	5/13/68	34-0-4100	2500
Conoco	Katy	11/05/69	4665-4675	*
Exxon	Katy	1/16/63	4350-4370	2000
Exxon	Katy	11/01/56	3760-4478	2350
Exxon	Katy	9/29/69	3600-4700	2300
Exxon	Katy	9/29/69	3600-4700	2300

FORT BEND

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Brown & McKenzie	Clodine	1/17/69	3210-3500	2860
Brown & McKenzie	Clodine	5/06/53	5750-5835	2800
Pennzoil Prod. Company	Fushear	11/25/68	5273-5490	*
French Oil & Gas Company	Blue Ridge	5/15/69	3450-3530	*
Merchantile Oil & Gas Company	Blue Ridge	9/03/74	2615-2630	1700
Oil & Gas Investments	Blue Ridge	8/16/71	2700-2740	1600
Oil & Gas Investments	Blue Ridge	1/23/69	2650-3060	1600

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

FORT BEND (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Oil & Gas Investments	Blue Ridge	5/23/74	4286-4300	*
Ramco Oil Company	Blue Ridge	6/14/72	1980-2090	*
Space City Oil Operators	Blue Ridge	6/30/69	3490-3500	200

BRAZORIA

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Amoco	Hasting	1/02/52	2100-3050	1140
Amoco	Hasting, W.	10/10/74	2100-5100	1200
Amoco	Hasting	1/15/74	2710-3225	1200
Amoco	Hasting, W.	12/05/72	2200-5300	1200
Amoco	Hasting, W.	6/29/70	2000-4950	1200
Amoco	Hasting, W.	1/30/70	2200-5100	1600
Amoco	Hasting, W.	2/13/61	1750-4985	1140
Amoco	Hasting, W.	12/05/72	2300-5600	1600
Amoco	Hasting	10/09/74	2100-5000	1700
Amoco	Hasting, W.	9/30/53	4040-5200	1140
Amoco	Hasting	7/27/50	4000-5200	1140
Amoco	Hasting, W.	10/07/74	2100-5200	1140
Amoco	Hasting	7/27/50	1900-2445	1140
Amoco	Hasting	8/28/52	4600-5200	1100
Amoco	Hasting, E.	7/24/73	2300-5300	1200

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

(cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Amoco	Hasting	11/15/52	4450-5200	1140
Amoco	Hasting, E.	11/03/69	2000-5200	*
Amoco	Hasting, W.	10/21/70	2300-5000	*
Amoco	Hasting, W.	1/27/71	2200-5100	*
Amoco	Hasting	2/17/58	1400-5225	1140
Amoco	Hasting, W.	2/02/75	2100-4900	1200
Amoco	Hasting, W.	5/14/70	2000-5200	*
Amoco	Hasting, W.	10/09/74	2100-4900	1700
Amoco	Hasting	8/24/55	1400-5450	1140
Amoco	Hasting, E.	7/24/73	2400-5200	1200
Amoco	Hasting	8/24/55	1500-5200	1140
Amoco	Hasting	11/05/51	4800-5250	1140
Amoco	Hasting, W.	3/22/71	2900-5200	1200
Amoco	Hasting	8/24/55	1350-4900	1140
Amoco	Hasting	8/24/55	1400-2200	1140
Amoco	Hasting, W.	10/09/74	2100-5300	*
Amoco	Hasting	6/22/64	3500-7200	1140
Amoco	Hasting, E.	1/28/59	1900-5200	*
Amoco	Hasting	6/30/55	2174-4950	1140
Amoco	Hasting, E.	7/19/54	1900-3050	1140
Amoco	Hasting	5/19/55	1350-3400	1140

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

BRAZORIA (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Amoco	Hasting, W.	5/11/70	1950-4900	*
Amoco	Hasting	--	*	*
Amoco	Hasting, E.	9/27/73	2300-5200	1200
Amoco	Hasting, E.	12/05/72	2300-5200	1200
Amoco	Hasting, E.	5/10/71	2300-5200	1700
Amoco	Hasting, E.	3/7/73	2300-2700	1200
Amoco	Hasting, E.	12/29/69	2000-5300	*
Amoco	Hasting	8/24/55	1400-5250	1140
Amoco	Hasting, E.	12/22/75	2900-5360	*
Amoco	Hasting, E.	11/19/73	2300-5200	1200
Exxon	Hasting, W.	11/24/75	2340-4300	1600
Exxon	Hasting	9/22/76	2500-4900	1930
Exxon	Hasting, E.	11/25/68	2100-5000	1200
Exxon	Hasting, E.	3/01/73	2100-5400	1200
Exxon	Hasting	9/01/53	2718-2728	1300
Exxon	Hasting, E.	5/12/75	1830-4300	1300
Exxon	Hasting, E.	8/09/43	3142-3172	*
Exxon	Hasting	9/24/53	1900-3100	1300
Exxon	Hasting, E.	4/02/63	2550-4400	1300
Exxon	Hasting, E.	5/06/74	2300-4300	1200

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

BRAZORIA (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Exxon	Hasting	10/29/53	1800-3100	1300
Exxon	Hasting	7/02/53	2000-2816	1300
Exxon	Hasting, W.	5/12/75	2200-4300	1600
Exxon	Hasting, W.	11/07/75	2080-4300	1300
Exxon	Hasting	6/26/52	2858-2898	1300
Exxon	Hasting	4/14/53	2000-3000	1300
Exxon	Hasting, W.	12/11/67	1750-5250	1200
Hasting Oil Company	Hasting, W.	9/15/69	2300-3050	1140
Pearland Oil Company	Hasting, W.	9/30/76	2550-3200	1400
AMOCO	Manvel	9/06/60	1650-2300	1600
V. W. Bowles & Company	Manvel	8/09/63	2000-3100	1650
Manvel Disposal Company	Manvel	12/01/75	2000-3100	1650
Gulf	Manvel	4/27/64	2405-2435	1150
Lenoir M. Jasey	Manvel	6/20/68	1950-2850	1600
Robert B. Powell	Manvel, N.W.	12/06/68	2000-2370	*
Texaco	Manvel, Miocene	2/08/73	4420-4760	1900
Texaco	Manvel	1/07/75	2550-5000	2000
Texaco	Manvel	9/23/76	2300-2950	1850

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

BRAZORIA (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Texaco	Manvel	--	2120-3215	*
Texaco	Manvel	9/23/74	2060-2340	1850
Texaco	Manvel	2/08/73	2100-3100	1900
Texaco	Manvel	8/25/64	2000-4900	1650
Texaco	Manvel	11/11/74	2050-4520	1500
Texaco	Manvel	3/09/64	2448-3260	*
Texaco	Manvel	--	2000-3550	*
Texaco	Manvel	5/14/71	4100-5100	2000
Texaco	Manvel, Miocene	11/27/72	2600-3100	1900
Texaco	Manvel	3/09/64	2600-3700	1850
Texaco	Manvel	--	4700-5018	1900
Texaco	Manvel	10/10/74	4600-6070	2000
Texaco	Manvel	11/11/74	2115-2780	1620
Texaco	Manvel	12/13/71	4240-4500	*
Texaco	Manvel	11/11/74	2300-4060	1670
Texaco	Manvel	12/13/71	4150-4480	*
Texaco	Manvel	12/05/72	2600-3200	1900

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Shell	Dear Park Area	5/17/57	6900-7650	2500
Industrial Gas Supply	Alco-Mag	7/13/67	3570-3708	2842
Russel MacGuire	Alco-Mag	1/26/68	3580-4200	2850
ARCO	Bammel	3/22/57	2600-3040	2300
Oil Lease Operating Co.	Cedar Bayou, N.	7/03/73	5690-5704	1500
Exxon	Clear Lake	8/09/63	1750-1885	1450
Exxon	Clear Lake	8/09/63	1750-1885	1450
Exxon	Clear Lake	5/30/72	1900-2300	1400
Exxon	Clear Lake	10/02/74	2150-5700	1400
Exxon	Clear Lake	9/19/72	1980-5210	1500
Acco Oil & Gas Company	Clinton	9/10/76	4930-4939	*
Amoco	Clinton	8/12/54	3350-3450	2500
Energy Reserves Group, Inc.	Clinton	6/28/76	3602-3608	2800
Lively Expl. Company	Clinton	7/18/72	3000-3450	2250
Williams B. Roberts, Inc.	Clinton	10/10/72	3950-3960	2300
Universal Pet. Corporation	Clinton	5/22/75	2900-3440	2200

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
James A. Whitson, Jr.	Clinton, S.	8/07/72	3000-3450	2400
Akins & Ownes	Deckers Prairie, S.	6/30/64	3910-3935	2400
W. S. Thompson	Deckers Prairie	8/08/55	2227-4000	1700
W. R. Godsey	Delhi, N.	2/05/68	6924-6967	2315
W. L. Puls	Delhi, N.	8/03/72	3950-3980	2400
Texaco	Durkee	7/24/69	2300-3941	2750
Amoco	Durkee	5/04/66	5490-5540	2550
Amoco	Durkee	5/18/76	2800-4662	2500
Reece Anderson	Durkee	4/30/53	2752-2780	2050
Pennzoil	Durkee	2/27/57	3155-3205	2600
Pennzoil	Durkee	2/17/67	5530-5593	*
Pennzoil	Durkee	9/22/71	4000-5600	*
Driscoll-Wells Prod. Company	Dyersdale	4/16/74	3025-3094	1870
Driscoll-Wells Prod. Company	Dyersdale	4/16/74	3792-3850	*
A. B. Marshall	Dyersdale	6/13/73	3062-3114	2520
A. B. Marshall	Dyersdale	5/16/73	3152-3114	2330
W. Mengen	Dyersdale, N.	5/24/74	3120-3172	2520
W. Mengen	Dyersdale	6/09/76	3615-3860	2900

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
W. A. Stockard	Dyersdale	10/06/75	3650-3700	2550
George T. McGhee	Eureka Heights	10/23/67	5440-5486	2650
Amoco	Fairbanks	11/17/53	3100-5200	2450
ARCO	Fairbanks, N.	6/09/76	2850-5400	2550
Crystal Oil & Land Company	Fairbanks, S.W.	9/28/61	6844-6857	2950
Kirbey Pet. Co.	Fairbanks, S.	1/27/54	3580-3660	2790
Rowan	Fairbanks, N.	7/05/56	2920-2970	2100
Union Prod. Co.	Fairbanks	5/17/57	5030-5095	2200
Union Prod. Co.	Fairbanks	11/14/63	3000-3025	2600
Gulf Oil Corp.	Goose Creek	10/25/72	5014-5531	1200
Monsanto Co.	Goose Creek, E.	8/03/70	1700-2300	*
Monsanto Co.	Goose Creek	3/19/70	1900-2700	*
Monsanto Co.	Goose Creek	12/29/72	1900-2700	1100
Monsanto Co.	Goose Creek	8/03/70	1900-2500	*
Monsanto Co.	Goose Creek	8/03/70	1700-2300	*
Monsanto Co.	Goose Creek	11/22/72	2000-2300	1200
Monsanto Co.	Goose Creek	5/30/75	*	*
B. M. Hester	H. H. H.	9/24/73	3510-2765	2500
Exxon	Hasting	4/27/54	2000-2900	1300

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Michael V. Kelly	Haokley	10/22/46	*	*
Amoco	South Houston	3/25/68	4537-5800	2400
Amoco	South Houston	8/03/67	5000-5400	1400
Jud-Oil Co., Inc.	South Houston	9/04/73	4400-4430	2450
Pennzoil	Houston, N.	12/28/63	5000-5400	1400
Texakota	Houston, S.	7/18/72	3190-3200	2250
Union Prod. Co.	Houston, S.	7/30/68	2950-3270	2500
James B. Field	Huffsmith, E.	12/16/69	2944-2954	2000
Flagg-Redfern Oil Company	Huffsmith	11/15/74	3642-3710	1750
Flagg-Redfern Oil Company	Huffsmith, E.	8/05/75	3562-3950	1750
Midhurst Oil Corporation	Huffsmith	8/23/67	2350-2500	1700
John Alexander	Humble Light	4/02/75	2660-2800	2100
Christi Mitchell	Humble Light	5/11/75	2150-2245	1600
Clifton Thomas Oil Prod.	Humble Light		3300-4300	*
A. W. Crosbey	Humble Light	7/05/51	1820-1890	1460
Conroe Oil & Gas Company	Humble Light	5/29/73	2085-2105	1575

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Deval Drilling Company	Humble Light	9/01/53	1150-1185	*
Exxon	Humble Light	12/15/62	2690-2819	2400
Exxon	Humble Light	1/13/54	2900-4100	2800
Jack Earl Oil & Gas Company	Humble Light	1/12/65	1070-1112	540
Jack Earl Oil & Gas Company	Humble Light	9/18/68	1056-1100	*
L. D. Cain Oil Company	Humble Light	9/14/64	2430-2450	*
Seco Pet. Corp.	Humble Light	8/06/68	916-923	380
Seco Pet. Corp.	Humble Light	11/26/75	*	*
Joe Silcox	Humble Light	8/16/67	653-659	300
Texaco	Humble Light	4/29/68	2600-2800	*
Texaco	Humble Light	11/16/55	1206-1346	1420
Texaco	Humble Light	11/22/72	1940-2200	1700
Texas Company	Humble Light	1/04/56	1273-1335	1420
Texas Company	Humble Light	3/26/51	3030-3041	1900
Texcolada Oil Company	Humble Light	2/16/52	1130-1160	*
Texcolada Oil Company	Humble Light	12/05/73	875-960	*
Tina Oil Corp.	Humble Light	7/19/73	1040-1060	720

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Traders Oil Co. of Houston	Humble Light	10/16/53	396-400	350
R. R. White	Humble Light	3/15/65	896-928	500
Wilson Oil Co.	Humble Light	3/28/68	1619-1656	870
Jim Riley	Joyce Richardson	7/30/65	3020-3100	2250
Reiter Foster Oil Corporation	Joyce Richardson	3/31/53	2985-3070	2400
Exxon	Katy	4/23/51	4448-4478	*
Exxon	Katy	5/07/76	3100-4480	2400
J. S. Abercrombie	Manvel	1/27/54	2300-3600	1100
J. M. Huler Corporation	Milton	1/11/60	3079-3128	2450
J. M. Huler Corporation	Milton	3/07/60	3396-3416	2450
Intercoastal Operating Co.	Milton	9/17/73	2870-3230	1700
John Alexander	Mykawa	6/09/76	2810-2965	*
John Alexander	Mykawa	8/10/73	3805-3965	2600
CRA Int'l. Inc.	Mykawa	7/31/74	8702-8710	*
Christi Mitchel	Mykawa	6/07/62	4250-4360	1800
Midhurst Oil Corporation	Peden	1/25/62	4065-4180	2000
J. S. Abercrombie Co.	Pierce Junction	1/09/51	1376-1378	2630

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Eastex Const. P & S Co.	Pierce Junction	9/14/54	2800-4150	2000
Jerald Eversdale	Pierce Junction	11/06/61	6740-7090	2700
Group Oil Co.	Pierce Junction	9/25/59	3000-4000	2650
Group Oil Co.	Pierce Junction	6/09/58	3200-3600	2650
Gulf Oil Co.	Pierce Junction	10/16/50	*	*
Curtis Hawkamer	Pierce Junction	11/10/65	3195-3340	2520
Lenoir M. Josey, Inc.	Pierce Junction	--	7000-7130	2600
Bryant Lang	Pierce Junction	8/24/72	4144-4154	2200
Magnolia Pet. Corporation	Pierce Junction	4/28/58	5855-5970	2800
J. T. Mantry	Pierce Junction	10/20/73	4365-4450	2250
Martin Oil & Gas Company	Pierce Junction	6/20/72	5542-5554	2700
Martin Oil & Gas Company	Pierce Junction	4/03/58	3640-4870	2580
Martin Oil & Gas Company	Pierce Junction	8/06/74	5500-5535	2600
Martin Oil & Gas Company	Pierce Junction	7/05/72	2890-3300	2250
C. F. Moore	Pierce Junction	9/20/74	3555-3585	2500
Sparta Oil Co.	Pierce Junction	8/25/72	1020-1060	450

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Texaco	Pierce Junction	3/10/60	4300-5700	2510
Wanda Pet. Corp.	Pierce Junction	4/17/72	860-1000	*
Xetron Minerals, Inc.	Pierce Junction	8/04/72	7263-7303	2550
John W. Mecom	Rankin	4/16/59	6340-6490	2700
Roberts & Whiston Pet,Inc.	Rankin, S.	2/13/69	3450-4200	2800
Amoco	Satsuma	9/14/73	2900-5200	2650
Amoco	Satsuma	6/23/76	2950-6868	1540
Amoco	Satsuma	6/19/68	6805-6868	*
Gulf Coast	Satsuma	3/12/56	2240-3100	2150
Phillips	San Jacinto	7/22/57	2750-3600	2700
Amerada Hess	Tomball	7/28/62	3844-3873	1750
Amerada Hess	Tomball	12/15/58	2723-2760	1750
Amerada Hess	Tomball	10/15/73	3450-3532	1750
Amer. Petrofina Co. of Texas	Tomball	11/16/70	5857-5869	1800
Exxon	Tomball	9/12/58	2280-3952	1800
Exxon	Tomball	6/16/67	2250-4000	1700
Exxon	Tomball	8/31/59	2100-4000	1800
Exxon	Tomball	8/25/70	2300-4200	2200
Exxon	Tomball	9/22/76	2300-3900	1900

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
Exxon	Tomball	2/06/58	2400-4000	1800
Exxon	Tomball	10/23/67	3500-4100	2100
Exxon	Tomball	5/28/70	2300-4000	1400
Exxon	Tomball	8/08/60	2250-4000	2100
Exxon	Tomball	11/22/65	3200-4000	2100
Exxon	Tomball	10/27/69	2250-4000	1700
Exxon	Tomball	4/26/63	2100-3800	2000
Exxon	Tomball	6/08/73	2250-4000	1900
Exxon	Tomball	6/17/74	2265-4300	1900
Exxon	Tomball	5/01/64	3800-3870	1900
Exxon	Tomball	1/30/76	2400-4200	2000
Midhurst Oil Corporation	Tomball	12/22/70	2550-2768	*
Nickols Oil & Gas Company	Tomball	6/30/64	2230-4300	1900
Shell Oil Co.	Tomball	10/18/71	3180-4000	2500
Sun Oil Co.	Tomball	9/23/75	2200-4200	*
Sun Oil Co.	Tomball	8/17/59	3570-3590	1800
Texaco	Tomball	5/26/67	3680-4800	1700
Texaco	Tomball	5/06/74	2250-2420	*
Texaco	Tomball	10/10/74	3000-3900	1700

* Not Given in Permit

TABLE III-1
(cont.)
BRINE DISPOSAL WELLS (5)

HARRIS (cont.)

Owner	Field	Permit Date	Injection Zone (feet)	Fresh-water Depth (feet)
H. E. Williams	Tomball	10/14/76	3300-4100	1820
Exxon	Webster	--	3130-3260	1450
Exxon	Webster	10/02/74	2130-5230	1000
Exxon	Webster	9/26/75	2130-5250	1500
Exxon	Webster	6/25/76	2130-5250	1500

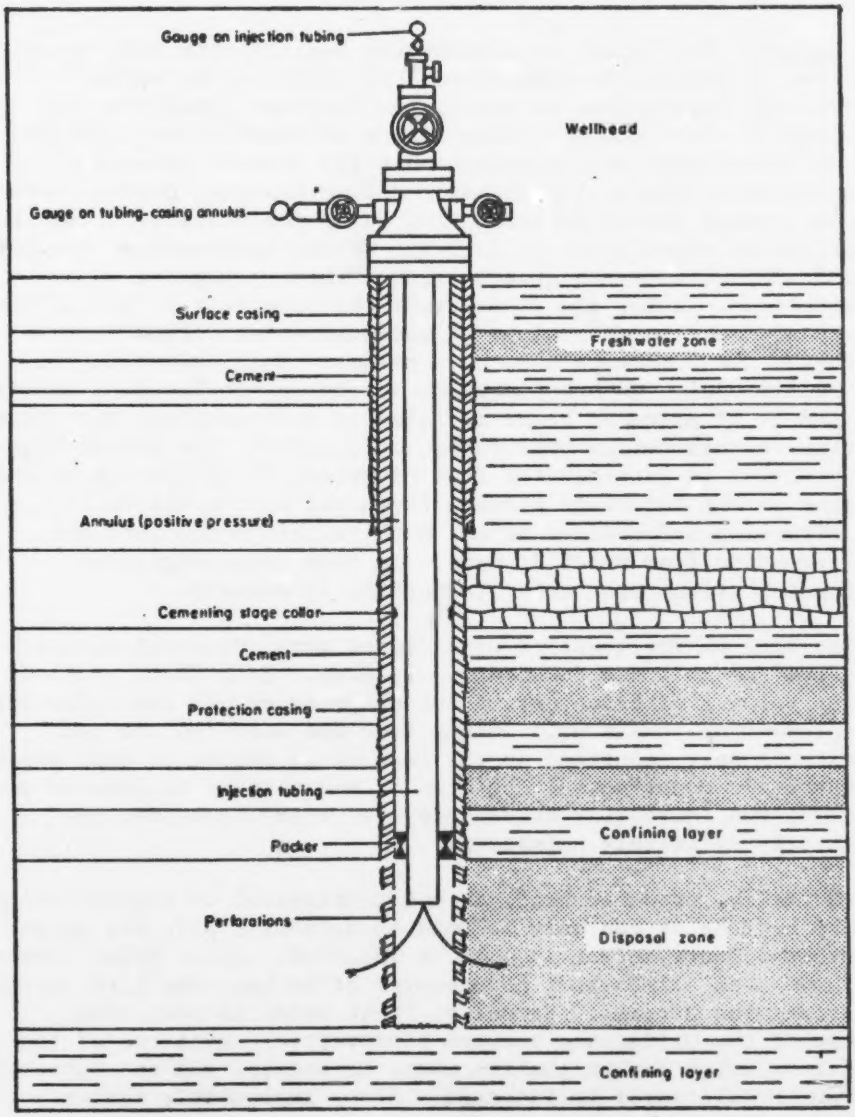
Gauge on injection tubing
Wellhead
Gauge on tubing-casing annulus
Surface casing
Fresh water zone
Cement
Annulus (positive pressure)
Cementing stage collar
Cement
Protection casing
Injection tubing
Confining layer
Packer
Perforations
Disposal zone
Confining layer

FIGURE III - I (6)

TYPICAL INJECTION WELL

and the protection casing and the tubing packer, installed above the disposal formation, are essential to insure that contamination of fresh water aquifers does not occur. The injection wells are pressure tested to detect leakage, an indication of possible or potential contamination of other aquifers.

Impact. The impact on groundwater quality from salt water injection is negligible with proper operation of the wells. Criteria and regulations as set by the Railroad Commission of Texas will control future contamination of fresh water aquifers. However, the danger of contamination still remains because of potential injection well problems: packer leakage, casing corrosion and cement sheath deterioration which individually or together can result in significant pollution. Proper maintenance, monitoring and surveillance can greatly reduce these potential causes of contamination. Also, the capacity of the reservoir to accept the present and anticipated volume of produced water without overpressuring the formation must be considered when selecting the zone of disposal. Though the exact volume is not known, a substantial amount of produced brine is injected into aquifers that have not been depressured by hydrocarbon production. The hazard from this practice is interaquifer flow of brine, or alteration of the position of the interface between fresh and saline waters.(2) When disposing of produced brine, much is reinjected into the same formation from which it came. In this case, negligible detrimental effect upon other formations is assured.

No data on the quantity of produced water disposal is available from the Railroad Commission of Texas. Each field produces varying volumes of brine per barrel of produced oil and individual well production levels will change from one month to the next. Quantity is only important in the case of an injection well which is improperly constructed, operated or monitored. As long as the formation can adequately accomodate the volume injected, the quantity is relatively unimportant.

Normally, produced brine is not detrimental to surface water quality because it can only be held in detention pits for up to seventy-two hours before it must be injected. Since brine disposal pits have been eliminated, no produced brine has come into contact with receiving streams. Normally, fresh water is protected because of the difference between piezometric elevations of the aquifer in which higher quality water is located and the formation into which salt water is injected. Also, impermeable shales which lie above and below the formations act as barriers to movement of water.

The future problem related to produced brine disposal by wells is eventual overloading of the capacities of disposal formations. Evidence indicates that the production ratio of brine to oil greatly increases as an oil field is depleted; therefore, greater amounts of salt water will require disposal. Existing zones of disposal will be overloaded by their continued use as brine injection increases. Careful consideration of future loading of these disposal aquifers is needed to avoid any pressure buildup caused by formation overloading.

Therefore, brine disposal through injection wells has no significant impact on the surface water quality in the Greater Houston 208 Planning Area; and as long as the pressure buildup in injected formations remains within limits to insure proper operation of the injection wells, no harmful effects to the existing aquifers will occur.

Brine Disposal Into Tidal Waters

Introduction. Tidal disposal requires separating the crude oil from the produced water and then releasing the water to tidal basins for dispersal into the bays.

Operation. The brine produced with the crude oil is first pumped to mechanical separators for removal of most of the oil from the brine. The relatively oil free water is then piped to a skimming tank, or a series of tanks depending on the operation of the oilfield, so that the less dense oil can be removed even more. The produced brine is then discharged into the surrounding bay water.

Control. All brine discharged into tidal waters requires a permit from the Railroad Commission of Texas and the Environmental Protection Agency. Before a permit is issued by the Environmental Protection Agency, a complete analysis of the salt water to be released must be sent to the agency and reviewed by them. The requirements by the Railroad Commission of Texas for leases disposing of oil field brine into tidal water are as follows:

1) Each permit must be reviewed and renewed annually.

2) Sufficient collecting and skimming pits must be maintained to prevent any oil from entering tidal waters. Only those pits that are absolutely necessary for the proper skimming of this oil will be permitted. Accumulations of free oil and basic sediments shall be removed immediately and the pits maintained in such a manner that there is no danger of lateral seepage or overflow at any time.

3) All collecting pits shall be lined with an impervious material, acceptable to the Commission, in the event shallow fresh water sands are present in the area.

4) Discharge of all produced oilfield brines into tidal waters, channels, water control floodways, or similar systems, shall be through a closed system and shall be clearly marked at the point of discharge with the name of the operator and the name of the leases from which this water originates.

5) In the event produced oilfield brine is delivered into a flood control ditch or similar waterway, written permission must be filed with the Commission from the authority in charge.

6) Each system must be inspected by District personnel subsequent to initial approval and be reinspected each year prior to renewal. In the event protests are received from landowners or other regulatory bodies, a hearing will be called.

7) Samples of the discharged brine must be taken at random times by a qualified analyst and a report filed quarterly with the District Office showing the oil content. No more than forty (40) days should lapse between sampling dates.

Impact. The maximum allowable concentration, as set by the Railroad Commission of Texas, of oil in the brine is 20 ppm. The average concentration is usually between 5 to 15 ppm when samples are analyzed. The quantity discharged is not recorded by the Railroad Commission of Texas and therefore the total amount of crude oil discharged into tidal waters can not be estimated. At the present time there are no tidal disposal operations in Harris County and the only oilfield located in the Planning Area near the Gulf is Gilack in Galveston County. No estimate can be found for the amount of brine disposed in the tidal waters, and therefore the impact on tidal water can only be estimated. Given the dispersal of the Gulf, concentration of oil resulting from brine released will be extremely low. However, studies have shown that cell division of phytoplankton was inhibited by concentration of crude oil ranging from 0.01 ppm to 1,000 ppm.(3)

Solid Waste

Introduction. Solid waste, as discussed herein, is defined as any material used in drilling operations or oil production that must be discarded and disposed of. Drilling operations will yield almost all of the solid waste that would contribute to any significant impact on water quality. Solid waste would include such items as the drilling mud including additives used in drilling, trash, tubing, broken tools, crude, and miscellaneous items during the operations.

Impact. Proper disposal during operations and adequate clean-up procedure employed by the companies can and have eliminated the possibility of most of the solid waste from reaching receiving streams. Drilling mud, however, can be detrimental to stream quality if proper disposal techniques are not used. Drilling mud consists of the material from the hole itself plus additives employed during drilling operations. This drilling mud is either left at the site, spread over the fields, or possibly taken to another job to be reworked in other drilling operations. At current prices, it is estimated that the large majority of the drilling mud is resold to other drillers. The practice of spreading the drilling mud onto nearby fields raises the possibility of having portions of the mud eroded into nearby streams. No studies were found that showed any quantity or impact upon stream quality. Impact would be related to type of additive used, material excavated, erosion factor, application onto soil, and the proximity to receiving streams. In much of the planning region, the wells dug are in flat farming lands and the drilling mud is easily worked into the fields and becomes part of the top soil.

Oil Spills

Introduction. Accidental oil spills or oil leakages are considered nonpoint pollution sources by its degradation of stream or bay waters and from a source that is not a constant discharge point. Oil spills can occur at any location where oil is available from production to refining, but the majority of oil spilled is from transportation, notably vessels.(7) Vessels make up the largest single source of oil spilled and are usually large spills (over 100,000 gallons per occurrence). In 1975, the annual volume of spills in the United States including coastal waters was about 22 million gallons. Of this total, 16 1/2 million gallons were attributed to 20 spills and the balance were attributed to 11,976 spills.(7)

Regulation. Any oil spill by any producer, no matter what quantity, is reported to the Railroad Commission of Texas, the Environmental Protection Agency, the Texas Water Quality Board, and in tidal waters, to the Coast Guard. Enforcement of the regulations regarding oil spills and the measures to prevent these occurrences are through fines levied for any offenses and also through the effective means of stopping production of crude oil by the Railroad Commission of Texas until remedial action is taken. Oil spills are costly to the offender through fines, clean-up operations, (which the producer has to pay if found to be guilty) and loss of production. Also, federal efforts of enforcement may carry criminal and/or civil penalties.

Impact. The amount of crude oil discharged by accidental spills will determine the significance of impact on stream or bay waters. Crude oil, itself, may contain thousands of compounds, and will differ markedly in their composition and physical properties, therefore when released to the marine environment, these compounds react differently. Some are soluble in water; others evaporate from the sea surface, form extensive oil slick, or settle to the bottom if sand becomes incorporated in the oil globule.(3) The mortality of birds, fish, shellfish, worms, crabs, and other crustaceans are direct and immediate from a major oil spill and studies have been made to investigate the total effects. In the spills that would be the most common for the parameters of this report, a limited impact occurs. It takes 320,000 gallons of air-saturated seawater for the complete oxidation of one gallon of crude oil.(3) Various bacteria and microorganisms eventually decompose the crude oil and any minor spill, after clean up operations, if large enough for it to be effective, will be reduced by the environment.

Oil released into streams or bays may be detrimental to water quality in the following ways:

1) Deleterious effects on domestic water supply by the production of tastes and odors; the presence of turbidity, films, or iridesence; hazards to the health of consumers; and the increased difficulty of water treatment.

2) Harmful effects on fish and other aquatic life by interference on the epithelial surfaces of the fish; destruction of algae and other plankton; coating bottom of waters interfering with spawning; deoxygenation of waters; and direct toxic action on fish or fishfood organisms.

In relation to possible oil leakages from individual wells through poor operational procedures or poor maintenance, no studies were found to properly evaluate the detrimental affects, if any, of surface or groundwater quality. Discussion with the Railroad Commission of Texas revealed that they did not have any available data on the subject. Water quality parameters measured by the various governmental agencies were insufficient to determine if any change in water quality has been generated by oil field production.

Impact of Abandoned Wells and Brine Pits

The potential contamination of fresh water aquifers through the deterioration of brine disposal wells by undetected ruptures in casing should also be considered for abandoned oil wells or test holes. For many years it was common practice in oil exploration to abandon test holes without proper plugging, thereby leaving a vertical pathway to various aquifers or formations.(4) Even though they are not brine disposal wells, potential impact can be significant if leakage from a saline aquifer to a fresh water aquifer is substantial. However, many of the abandoned wells cannot be located, and therefore cannot be inspected for possible leakage.

The use of brine disposal pits, except in emergency operations, has been terminated by regulations set by the Railroad Commission of Texas. Any specific use must be approved by the Commission and even then, the pit can be used for only 72 hours before the brine is required to be injected into the formation. Abandoned pits were to be backfilled by the oil operators. However, no data was found to verify that all pits were backfilled.

Preliminary Assessment of Injection Wells Impact

Summary

There are approximately thirteen (13) injection wells currently operating in the Greater Houston 208 Planning Area with no detrimental affects to ground or surface water quality. It is expected that additional wells will be constructed or placed into operation with no detrimental affect on water quality. The stringent design criteria and monitoring system established by the Texas Water Quality Board, together with excellent formations to be employed for injection zones, indicate that injection wells pose no significant threat to groundwater contamination.

Introduction

The number of industrial injection wells in the designated Planning Area has been increasing in the past several years. The latest count is approximately twelve, most of which are in Harris County. The majority of injection wells are owned by chemical plants and their waste are mostly acids, ammonia, and other plant wastes. Discharge permits show large differences in quantity of waste injected, and injection pressures range between 430 psi up to a maximum of 2,500 psi. The formations used for injection zones are generally located in the Miocene and Frio Sands which are located at depths greater than 4,600 feet.

Characteristics of Injection Wells

The various characteristics of industrial wastes; the operation with regard to pressure, quantity, temperature, of injection wells; and the formations in which the waste is injected requires individual consideration for each well. Figure III-1 shows a schematic diagram of an industrial waste injection well completed in permeable sand. An injection well includes the following: surface casing for protecting fresh water zones, protecting casing extending from the surface to a saline water aquifer of at least 10,000 parts per million dissolved solids concentration, cement between the casings and the borehole tubing for the flow of the injected fluids, annulus solution containing herbicides and bacteriacides, packer, perforated openings, and all mechanical equipment above ground for the injection and monitoring of the liquid wastes. A pressure gauge is required to monitor the pressure on the annulus between the injection tubing and the protection casing. Should a leak occur in the tubing or the packer seat, a pressure increase in the annulus during injection would be indicated by the gauge, and the malfunction can be corrected.(6)

The design of casing depends primarily on well depth, character of formations penetrated, fluid pressure, and the corrosiveness of the fluids that will contact the casing. Wastewater is injected through separate interior tubing rather than being in contact with the well casing all the way down to the disposal zone. A packer is set near the bottom of the tubing to prevent corrosive waste from going up the annulus and contacting the casing.(8)

Most wells are designed for a 20 year life expectancy but normal life for an injection well in Texas is approximately seven years.

Characteristics of Waste Suitable for Injection

In the Planning Area, there are a large assortment of wastes being injected into the saline waters. These are wastes for various types of chemical manufacturing and wastes from petroleum refining operations. They include alkalies, acids, chromates, sulfites, alcohols, phenols, cyanides, and chlorinated hydrocarbon. No investigation was found concerning the industrial brines for which there is no economical technical treatment process and chemicals which could possibly be treated above ground and then released into streams.

Some of the injected wastes have pretreatment such as sedimentation, pH adjustment, filtration, and BOD removal. This pretreatment is normally employed to prevent injection well damage.

Reactions such as the precipitation of alkaline earths and heavy metals from soluble salts may result in the plugging of pores causing a reduction in the permeability of the receiving formation.(9) It should be noted that optimal use of underground storage space could best be realized by use of well injection only where no economically satisfactory waste treatment or disposal is available.(8)

Aquifer Characteristics

Two major characteristics that any aquifer needs in order to be employed for the injection of liquid wastes are:

1) "A zone with sufficient permeability, porosity, thickness, and area to act as a storage reservoir; and"

2) "A zone that is vertically below fresh water circulation and confined by rock formations impermeable to waste liquids."(10)

These two characteristics are found in the Tertiary sands underlying the Planning Area. The knowledge of the vertical confinement and lateral movement of water within the injection zone is required to eliminate the possibility of salt water movement into the groundwater zone.

Impact

Control and Regulation. In the Greater Houston 208 Planning Area, the Texas Water Quality Board has jurisdiction concerning all aspects of deep well injection of all liquid wastes except brine produced during oil and gas production. Currently, the Texas Water Quality Board acts under the 1961 Injection Well Act, as amended. The Board reviews, records, and approves all permits received by applicants and rejects any permit application that cannot meet the established criteria. All permits are refused if the injection of liquid wastes would have any effect on the oil and gas production in the area or jeopardize potable groundwater supplies. Also, each applicant tests the liquid waste to be injected on the formation with boring samples to insure that precipitation does not occur rendering the injection zone incapable of receiving the wastewater. The Board also reviews all plans and specifications to insure that design criteria are met. The Board also inspects the construction of these wells so that approved plans and specifications are met. The wells are continually monitored by the owner and the data are reported to the Texas Water Quality Board twice a year. Instructions to applicants for injection well disposal are shown in Figure III-2.

FIGURE III-2

INSTRUCTIONS TO APPLICANTS FOR INJECTION WELL DISPOSAL

INSTRUCTIONS

1. Application form in quintuplicate, all accompanying data, and the required $25.00 filing fee shall be sent to the Texas Water Quality Board, P.O. Box 13246 Capitol Station, Austin, Texas 78711. The Board's staff is available for consultation should questions arise in completing the application.

2. Justification for subsurface disposal must accompany the application by submitting treatability studies of alternate methods of waste disposal. Explain in detail why each method is considered to be less satisfactory in terms of environmental protection than the proposed subsurface disposal method. Indicate whether this waste is presently being produced, and if so, what method is used in disposal. Briefly describe the manufacturing process(es) and product(s) from which waste will arise.

3. A technical report is required before an application can be processed. This report should include, but not necessarily be limited to the following information:

    a. An accurate plat showing location of proposed injection well relative to both state land survey and plant boundaries.

    b. A map indicating location and depth of water wells on and adjacent to plant property. This map or a supplementary map must show location of all artificial penetrations (oil and gas wells, exploratory tests, etc.) of the uppermost proposed injection interval(s) withn 2½ miles of the injection well site. (The technical staff may adjust this distance as the situation warrants.)

    c. Description of local topography and geology pertinent to injection program. Depth of deepest strata containing fresh water or water of suitable quality for potential beneficial development as determined by well development and/or electrical logs.

    d. A detailed description of the chemical and physical characteristics of the waste to be injected. Complete chemical analyses of all inorganic constituents should be reported in ppm or mg/l. If organic fractions are present, all such constituents should be reported in ppm or mg/l. as individual percentages by weight, or in other appropriate terms. Give analysis of each waste stream and its percentage of total waste.

    e. The anticipated average and maximum rate of injection in gallons per minute. Estimated yearly volume of injected waste and anticipated life of project.

    f. Data on construction, completion and operation of proposed injection well.

        (1) Total depth

        (2) Casing—size, grade, type, weight and setting depth of all strings; size and type of tubing; name, model, and depth of tubing packer setting.

        (3) Cement—type and volume of cement to be used on each casing string and calculated top of cement behind each string. Describe and give percent of all cement additives.

        (4) Proposed injection interval(s) and perforations or screen setting depths. This should include the interval(s) to be utilized initially and the entire zone requested for future development.

        (5) Diagramatic sketch of proposed wells including the wellhead.

        (6) Anticipated maximum and average wellhead injection pressures.

        (7) Description of possible hydraulic fracturing and/or acidizing programs, if anticipated.

        (8) Description of proposed injectivity tests.

        (9) Proposed logging, bottom-hole testing, coring, etc.

    g. Characteristics of injection interval(s):

        (1) Lithology, porosity, permeability, temperature.

        (2) Natural reservoir fluid pressure or hydrostatic head; fluid saturation and chemical characteristics; and fracture gradient or critical input pressure.

    h. Compatibility of injected waste and formation fluids.

    i. Calculated formation pressure increase by injected waste and directions of dispersion.

    j. Surface installations.

        (1) Detailed description of pretreatment process and facilities to be used (include flow diagram).

        (2) Description of type of materials to be used in pretreatment facilities and transmission lines.

        (3) Description and location of all waste retention facilities, if such are to be used in conjunction with the injection well.

4. In the event an existing well is to be converted to an injection well, applicant should submit a complete electrical log, all other logs or surveys performed on the well, and complete casing and cementing data.

5. Submit a list of adjacent landowners, their addresses, and a map indicating location of their property. (See Rules and Regulations, TWQB, Rule 305.1 (d))

Design. Several hydraulic and reservoir characteristics are reviewed before an injection well is approved by the Texas Water Quality Board and constructed by the applicant.

1) Compatibility

Compatibility between disposal formation and injected fluid must be assured so that the well can function properly. Problems of compatibility between the two are usually solved either by pretreating the wastewater or injection of a buffer fluid to separate the wastewater from the formation water.(6)

2) Radial Dispersion

The radial distance from the injection well can be calculated by the formula:(6)

$$r = \frac{Q}{h\phi}$$

Where: Q = quantity of fluid in cubic feet per unit of time
ϕ = porosity of the formation in percent
h = thickness of formation in feet

To illustrate, assume the following:

Q = 450 gpm or 633,000,000 cu. ft. in 20 years
ϕ = 30% porosity
h = 250 feet, sand thickness

Time of operation is generally computed for 20 years

$$r = \frac{633,000,000}{(3.14)(250)(0.3)} = 1,640 \text{ feet}$$

Once the injection ceases, the wastes will move according to natural rate of water movement in the salt water aquifers, normally between 5 to 50 feet per year. Movement through overlying formations of clay or shale upwards also occurs. This movement through the formation is estimated to range 0.01 to 0.2 feet per year.(6)

3) Pressure Increase

The pressure increase caused by an injection well causes fluid to rise in any connected open borehole. This pressure in the formation can be calculated by measuring the fluid level in a monitoring well, open to the formation, provided the specific gravity of the fluid is known.(6) The change of head of the potentiometric head can be calculated by the nonequilibrium method. The formula, derived by Dr. D. V. Theis, and modified by L. K. Wenzel, is as follows:

$$s = \frac{114.6\ Q}{T} W(u)$$

Where:

s = change of head in feet of the potentiometric surface
Q = quantity in gallons per minute
T = transmissivity
W(u) = is obtained by integration of Theis formula

This formula is based on assumptions of idealized situation which do not exist in nature and ignores other relatively insignificant factors that may affect total pressure change. However, it is a method employed to compute expected pressure increases within reasonable limits.(6)

4) Storage Coefficient

The storage coefficient is the volume of water that is released or taken into storage, per unit surface area of an aquifer per unit change in the component of head, normal to that surface.(6) The coefficient of storage of an aquifer can be determined from pumping tests in an aquifer, if there are one or more observation wells to measure the rise or fall of the potentiometric surface over a period of time, and provided the pumping rate is constant.(6) If this method is not available, then the coefficient of storage can be computed by the formula modified after C. E. Jacobs as follows:

$$S = fw\ \phi\ m\ (a + \frac{B}{\phi})$$

Where:

fw = weight of one cubic inch of formation water at stated temperature in pounds
ϕ = porosity of aquifer
m = thickness of saturated aquifer in inches

B = bulk modulus of compression or elasticity of aquifer skeleton
a = bulk modulus of compression of aquifer water

Information for some parameters is available mostly from the petroleum industry and therefore can be obtained for most formations with good accuracy.(6) The coefficient of storage can also be derived from the nonequilibrium method.

5) Summary

As shown by the brief explanation of the major design considerations for injection of fluids into Texas aquifers, estimates with relatively good accuracy can be computed to determine how an individual well will function and what happens to the waste fluid after injection. Prediction of future conditions when modified by injection well disposal operation supplies the Texas Water Quality Board with one means of judging the impact of these operations.

Assessment of Impact. Two results of the use of injection wells which can be predicted to occur in every case are the modification of the groundwater system and introduction of fluids that have a chemical composition different from the receiving water in the injected formation.(11)

The main question concerning these two results is if any environmental damage to the aquifers has been or will be done with the continued use of injection wells. Evaluation of the present or future problems will result in the study of the hydrogeological charactertistics of the receiving and surrounding aquifers and the chemical composition and quantity of the injected wastes. In the case of injection well operations in the Greater Houston 208 Planning Area, the injected formations will not be used for water withdrawal and any modification of the formation by injected fluids will not affect the existing or future groundwater resources of the state. That is, these formations are never expected to be a potential supply of water for any manmade purposes; therefore, the quality of the formation's water is of little concern.

Modification of the groundwater system is contained near the formations of the injection operation. The pressure increases due to the injection well do not affect the groundwater that is used as a water supply. After the injection well is discontinued the pressures are relieved and eventually return to natural conditions, estimated to be about the same time it took for the buildup to occur. The movement of injected fluid along with the formation's water through overlying layers of clay or shale in order for the contamination of groundwater supplies to occur has been estimated to be in a range of 0.01 to 0.2 feet per year through clay or shale formations.(6) However, these rates are theoretical and may be even less by the indication that the formation's water is not affecting groundwater supplies at the present time but is contained in the lower aquifers.

Impacts that could occur in individual cases are:

1) Degradation of groundwater quality;

2) Contamination of other resources;

3) Chemical reaction between wastewater and natural water; and

4) Chemical reaction between wastewater and minerals of disposal zone.(9)

The greatest concern is the contamination of groundwater. The three principle ways of contamination to occur are the following:

1) Escape of wastewater up the wellbore because of failure of the injection well casing;

2) Vertical escape of injected wastewater beyond the well casing, from the injection zone into a fresh water aquifer; and

3) Vertical escape of injected wastewater from the injection zones up improperly abandoned wells into freshwater aquifers.(9)

Because of the standards that must be met by each applicant for waste injection wells and the close monitoring system called for by the Texas Water Quality Board, there is little possibility for contamination of a groundwater aquifer. No potable groundwater contamination has occurred by an injection waste disposal well in the Planning Area. The depth of the wells in the area and the wide impervious layers separating the receiving sands with potable groundwater preclude the possibility of the wastes reaching fresh water aquifers. The shallowest injection well has a discharge depth of 3,000 feet, but most of the wells inject into the Frio or Miocene Sands at a depth of 4,600 to 6,000 feet. The deepest fresh water wells in Harris County are 2,000 feet deep located mostly in North Harris County where no injection wells exist. The fresh water wells located in the same general area of the injection wells are mostly less than 1,000 feet deep. At this time, there is no research to determine the maximum amount of liquid wastes that can be stored in these sands but because of the vast areas and the limited amount of operating wells, the limited storage capacity is not foreseen to be a significant problem in the immediate future. The only adverse environmental impact that these wells have would be caused by a leak of the well, subsequently contaminating the nearby water supply.

The safeguards now in effect for all operating wells precludes all but the most remote possibility of this occurrence. The detailed review process, the stringent design criteria, the supervision of construction, and the constant inspection of each injection well that presently exist in Texas should be maintained to ensure a very low probability of this occurrence. Injection wells can provide a satisfactory means of disposing untreatable industrial brines with no detriment to the surface water quality of potable groundwater supplies provided that the Texas Water Quality Board criteria is met.

Exhibit III-1 shows the location of existing operating injection disposal wells in the Greater Houston 208 Planning Area. Table III-2 gives various data for each well shown.

Preliminary Assessment of Salt Water Intrusion Impact

Summary

Salt water intrusion in the developed aquifers has continued in the area south of the Greater Houston 208 Planning Area due to the pumping of groundwater and reduction in the potentiatric head of the water formations. However, investigation indicates that except for some higher concentrations of chlorides in the very southern reaches of the Planning Area, the same water quality from producing wells has been maintained for at least the past thirty years in areas where there is possibility of salt water intrusion. Wells located further away from the southern boundary of the Planning Area show a decrease in chloride concentrations as compared to wells near the boundary.

Salt water encroachment in surface waters poses no threat to the water uses of the area. The natural tidal action in streams cannot be controlled by man and cannot be defined as a problem.

Introduction

Salt water intrusion can be found either in surface or ground water, and the conditions are controlled by the geologic

TABLE III-2

INJECTION WELL DATA (12)

PERMIT NO.	APPLICANT	TYPE OF WASTE	PERMITTED INJECTION RATE	INJECTION PRESSURE	DATE INJECTION BEGAN
33	Celanese Chemical Co.	Chemical Plant Waste	190 gpm	450 psi	10/31/76
34	General Aniline and Film Corporation	Aqueous Effluent from Chemical Manufacturing	145 gpm	430 psi	4/68
36	Arco Chemical Company	Manufacture of Metaxylene, 150 Phthalic Acid, MEK, SMA Resins	400 gpm	1,000 psi	3/69
38	Coastal States Gas Producing Company	Wastes Resulting from Plant Storage Brine Disposal Program	Not Available	Gravity Flow	4/68
45	Celanese Chemical Co.	Acetaldehyde, Acetic Acid, Chlorinated Acetaldehyde, and Water	67 gpm	500 psi	6/69
69	Celanese Chemical Co.	0.2% Acetaldehyde, 1.3% Acetic Acid, 1.9% Chlorinated Acetaldehydes, and 96.6% Water	250 gpm	450 psi	10/31/67
82	E. I. DuPont de Nemours and Company	Chemical Plant Wastes	260 gpm	<2,000 psi	9/28/72
83	E. I. DuPont de Nemours and Company	Chemical Plant Wastes	260 gpm	<2,000 psi	Not Available
86	Ethyl Corporation	Sulfuric Acid, Ammonium Sulfate Wastes Containing Cyanide and Organic Constituents	1,000 gpm	<2,500 psi	Not Available
89	Armco Steel Company	Consists of Two Streams from Napthalene Sump and Ammonialiquor	1,700 gpm	<2,500 psi	Not Available
90	Armco Steel Company	Consists of Two Streams from Napthalene Sump and Ammonialiquor	1,700 gpm	<2,500 psi	Not Available
99	Dow-Badische	Aqueous Solution of Organic and Inorganic Constituents from a Caprolactum Plant	150 gpm	400 psi	Not Available
122	Pennwalt Corporation	Chemical Waste	150 gpm	<2,000 psi	Not Available

and hydrologic characteristics of the area. In the Harris-Galveston County areas, the most acute problem arises in the fresh water aquifers because of the overpumping from wells causing salt water encroachment and the increase of saline concentration.

Geohydrology

The formations that contain the groundwater being pumped in the area are composed of sedimentary deposits of gravel, sand, silt and clays. These formations are in belts that parallel the shoreline of the Gulf of Mexico. All of the formations thicken downdip so that the older formations dip more steeply than the younger ones.(13) However, the occurrence of salt domes and faults may cause the thickening or thinning of individual formations locally. These salt domes may also cause local salt water contamination where the salt domes pierce the lower aquifers.

The major aquifers in the area are the Chicot aquifer, Evangeline aquifer, and the Burkeville confining layer. The Chicot aquifer includes all deposits from the land surface to the top of the Evangeline aquifer. The aquifer has been divided into an upper and lower unit, and the basal part of the Chicot aquifer in southeast Harris County and most of Galveston County is known as the Alta Loma Sand, which is heavily pumped. The Evangeline aquifer, which is the most important source of fresh groundwater in Houston area, consists of layers of sand and clay and is underlain by the Burkeville confining layer. This layer is composed mostly of clay but contains some layers of sand. The Burkeville restricts the flow of water except where it is pierced by salt domes and in the northeastern part of Harris County where it contains water-yielding sand layers. The Burkeville is underlain by the Jasper aquifer.(13)

Upstream Encroachment of Salt Water in Surface Waters

In the Planning Area the interaction of river flow and tidal currents coupled with the subsidence of land results in a net upstream movement of sea water in the fresh water streams. The waters tend not to coalesce but to form a distinct interface due to density differential. The position of the interface between fresh water and the sea water is dependent of channel geometry, stream discharge, and high tide height. The upstream migration of sea water changes the native faunal populations in the aquatic environment, increases corrosion of engineering structures, and possibly causes infiltration of salt water into the groundwater supplies and contamination of fresh water aquifers.

Impact on Surface Waters

Salt water encroachment of streams has not become a serious problem in the Greater Houston 208 Planning Area. The San Jacinto River has tidal interchange action from the Houston Ship Channel up to existing Lake Houston Dam. The Water Quality Management Plan for the San Jacinto Basin concludes that "salinity levels in estuarine areas are controlled by natural forces beyond the control of man. As a result, meaningful standards cannot be set." If these areas include all water under the effects of tidal action, salt water encroachment cannot be considered a serious problem. The two bodies of waters that have been most affected by man's activities are the Houston Ship Channel and the San Jacinto River. Other streams draining into the Gulf that may be affected by salt water encroachment have not been substantially altered by manmade acitivities and no serious problems are indicated. These streams are operating under natural conditions of tidal action.

The San Jacinto River has been altered with the dredging for the Houston Ship Channel and the construction of Lake Houston. Buffalo Bayou has been dredged to become the Houston Ship Channel. Because of the improvements in the channel, salt water encroachment has moved considerably upstream. However, the use of the Houston Ship Channel and the pollution load it now experiences from the industries along the channel indicates that any additional salt water intrusion will not significantly affect the shipping activities of the Houston Ship Channel. From the logs of wells in Texas Water Development Board Report No. 203, the shallow wells (less than 100 feet) may be experiencing salt water intrusion into the near ground aquifer from waters from the Houston Ship Channel. Concentrations of dissolved chlorides are greater for some wells near the Houston Ship Channel than those located farther away. However, this finding is based on limited data as shown on Table III-3. All wells, except the ones noted with an asterisk, are owned by the United States Geological Survey and are used for purposes on collecting water parameter data and not for public water supply. Location of these wells can be seen in Exhibit III-2.

TABLE III-3

CHLORIDE CONCENTRATION OF WELLS NEAR HOUSTON SHIP CHANNEL (17)

Well Number	Depth of Producing Interval (Feet)	Date	Chloride (mg/l)
65-15-915	8-14	June 14, 1972	980
65-16-922	102-110	June 15, 1972	458
65-15-922	102-110	April 10, 1973	464
65-22-230	45-61	June 13, 1974	47
65-22-333	24-44	June 12, 1974	610
65-22-334	279-294	July 10, 1974	26
65-22-335	188-198	July 11, 1974	30
65-23-130	309-319	January 21, 1974	27
65-23-131	167-172	January 23, 1974	39
65-23-132	35-45	January 24, 1974	300
65-24-215	246-256	August 06, 1974	36
65-24-216	108-118	July 03, 1973	350
65-24-217	76-86	July 03, 1973	400
65-24-323	30-35	November 13, 1972	6,300
65-25-324	57-62	November 16, 1972	5,600

Salt Water Intrusion of Aquifers

Under natural conditions, coastal aquifers discharge into the Gulf at or seaward to the coastline. An equilibrium at the interface of fresh water and salt water is established. This interface tends to be parabolic with the denser salt water underriding the fresh water. (See Figure III-3) The length of this intruded wedge of sea water varies inversely with the magnitude of the fresh water head. With the changes in the hydrologic conditions brought on by manmade action, this equilibrium is altered.

The main cause of salt water intrusion is overpumping of the aquifers, causing a decrease in the piezometric head of the confined aquifer and the lowering of the water table in the unconfined aquifer. The lowering of pressure causes salt water to move inland in the aquifer itself. If a fresh water aquifer is underlain by saline water, overpumping will cause the groundwater level to be lowered, which in turn can cause an upconing of the saline water into the aquifer. (See Figure III-4) Besides overpumping, the possibility of abandoned oil wells that have pierced

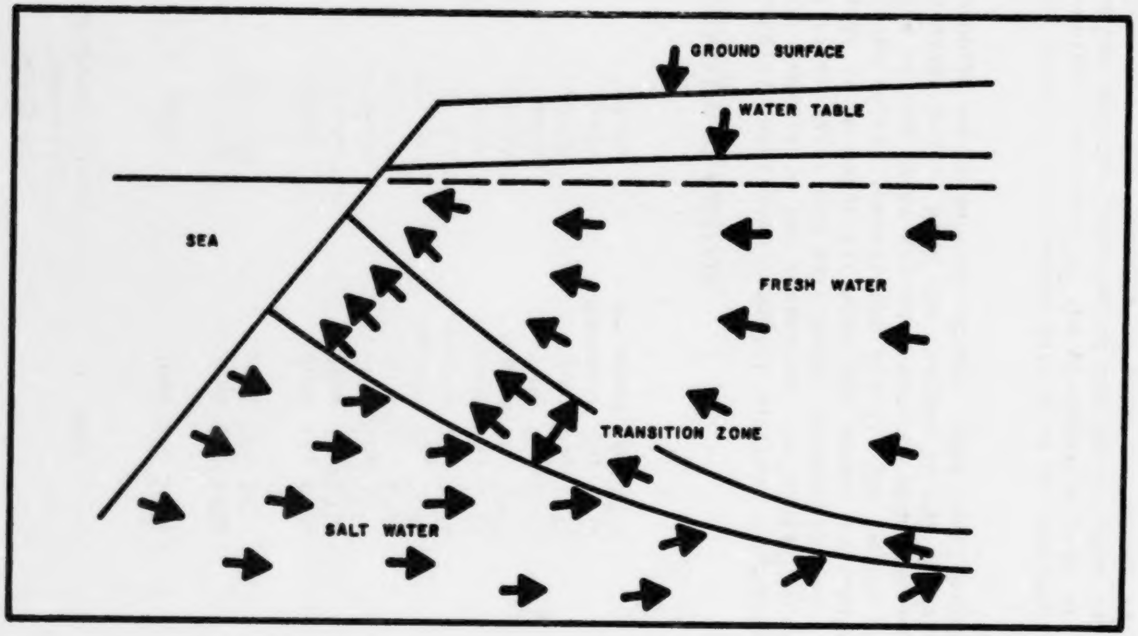
GROUND SURFACE
WATER TABLE
SEA
FRESH WATER
TRANSITION ZONE
SALT WATER

FIGURE III- 3
SCHEMATIC VERTICAL CROSS SECTION SHOWING FRESH WATER
AND SEA WATER CIRCULATIONS WITH A TRANSITION ZONE (14)

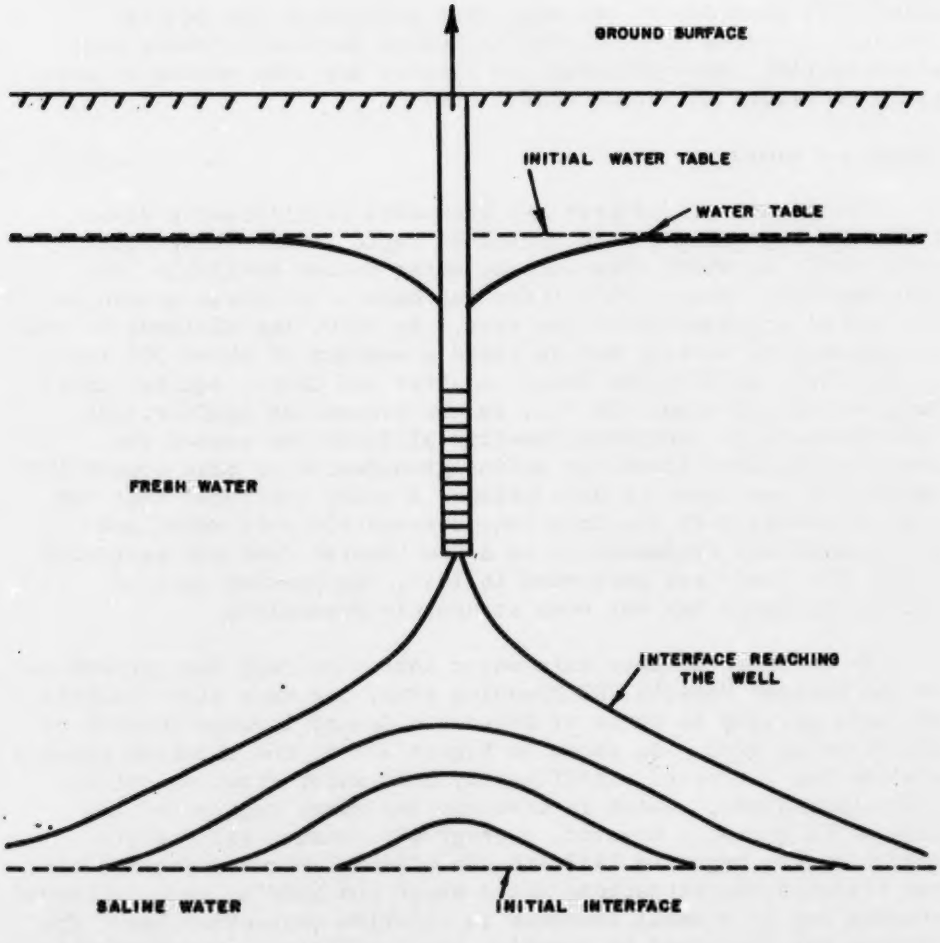
GROUND SURFACE
INITIAL WATER TABLE
WATER TABLE
FRESH WATER
INTERFACE REACHING THE WELL
SALINE WATER
INITIAL INTERFACE

FIGURE III- 4

SCHEMATIC DIAGRAM OF UPCONING OF UNDERLYING SALINE WATER TO A PUMPING WELL (14) the underground saline waters can provide a method of contamination of fresh water aquifer by the vertical migration of the waters. It should be noted that as little as two percent of sea water mixed with groundwater can make that portion of the aquifer unusable in terms of U. S. Public Health Service drinking water standard.(14) Once polluted, an aquifer may take months or even years to return to normal conditions.

Impact on Aquifers

The use of groundwater has increased significantly from 1937, the beginning of the period of rapid industrialization, until 1955, at which time surface water became available from Lake Houston. Since 1962, there has been a continued growth in the use of groundwater in the area. By 1970, the altitude of the potentiometric surface had declined a maximum of about 330 feet in the lower unit of the Chicot aquifer and Chicot aquifer undifferentiated and about 430 feet in the Evangeline aquifer.(13) This decrease in the potentiometric altitude has caused the interface between fresh and saline groundwater to move toward the centers of the cones of depression. A study concluded that the rate of movement of the interface between the salt water and fresh water was estimated to be a few hundred feet per year.(15) Since this study was performed in 1957, the present rate of lateral movement has not been accurately determined.

In order to discuss salt water intrusion into the groundwater of the Greater Houston 208 Planning Area, one must also consider the well pumping in parts of Galveston County located outside of the Planning Area. As shown in Figure III-5, the chloride concentration has increased significantly from water drawn out of the "Alta Loma Sands," which is used for the water supply for the City of Galveston. However, a program to reduce salt water intrusion was begun in 1953 and the effects were a reduction of the chloride concentrations until about the 1970's, when increased pumpage led to a small increase in chloride concentrations. The program was developed to consider the coefficient of transmissibility of the aquifers and to pump only into the upper portions of the aquifer where the chloride concentrations were lower. It is important to remember that saline water of various chloride concentrations at various depths underlays the entire Planning Area. Well Number 65-24-605 in Table III-4 shows this clearly by presenting the tests at various depths of a well located near La Porte, about three miles inland. This degradation of the quality of water of increasing depths exists naturally but is also influenced by the pumping of groundwater that causes cones of depression to occur. In 1899 a well screened from 756 to 796 feet, showed a chloride content of 244 ppm; whereas a nearby well, which is 860 feet deep, had a chloride content of 1,014 ppm.(18) These two

FIGURE III-5

CHANGES IN CHLORIDE CONTENT OF WATER FROM WELLS IN THE CITY OF GALVESTON'S "OLD" WELL FIELD IN THE VICINITY OF ALTA LOMA, GALVESTON COUNTY, 1934-61 (16)

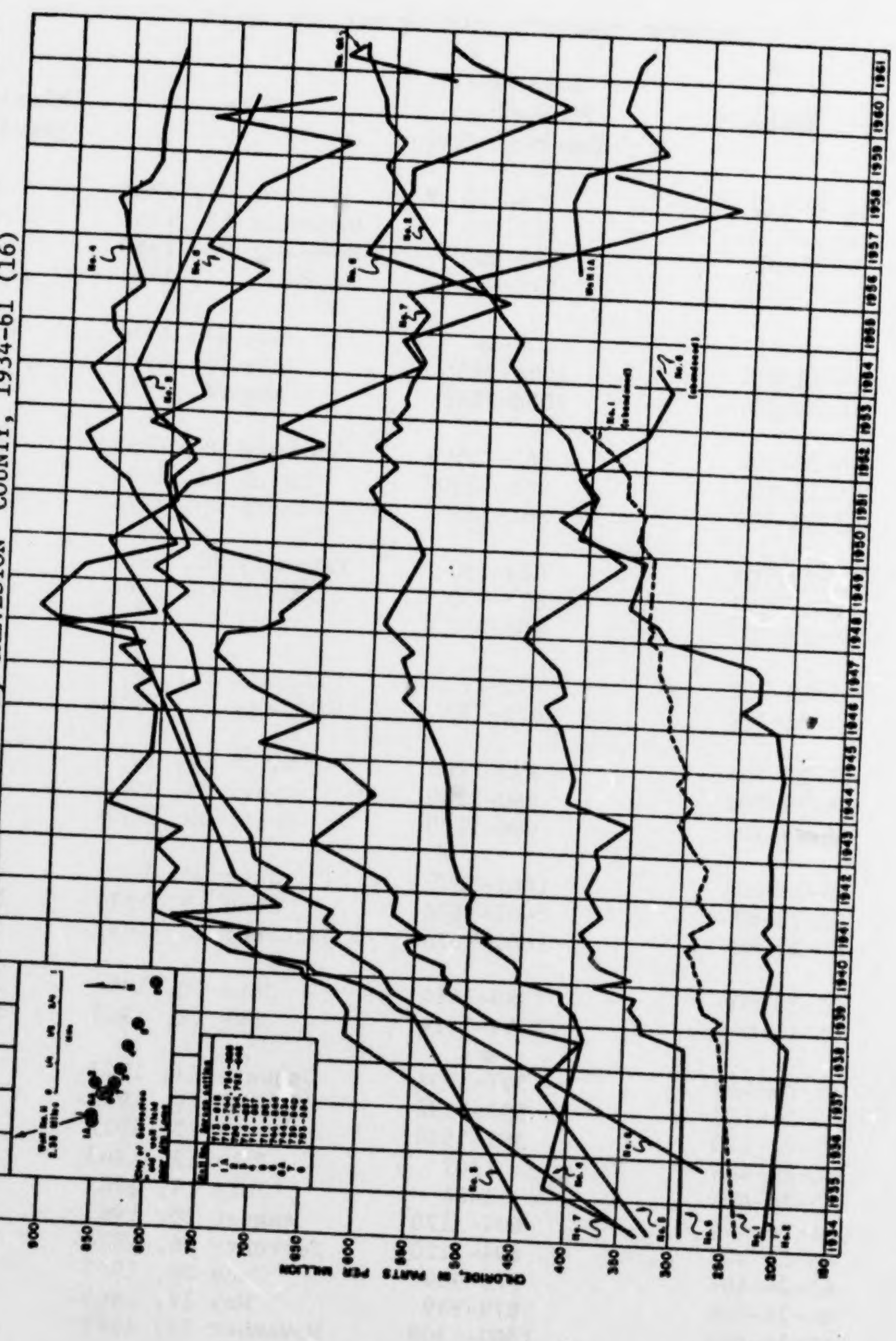

TABLE III-4

CHLORIDE CONCENTRATION OF VARIOUS WELLS (17,19,20)

Well Number *	Depth or Producing Interval (ft)	Date	Chloride (mg/1)
64-33-101	310-330	October 01, 1963	194
64-33-101	505-575	December 13, 1963	124
64-33-101	575-650	November 08, 1966	130
64-33-102	575-651	February 07, 1964	125
65-15-915	8-14	June 14, 1974	980
65-23-234	1006-1458	July 08, 1939	38
65-23-234	1006-1458	May 08, 1970	52
65-23-502	865-1550	February 06, 1953	96
65-23-502	865-1550	March 18, 1964	136
65-23-502	865-1550	April 06, 1971	120
65-23-703	803-950	February 09, 1951	59
65-23-703	803-950	March 18, 1960	62
65-23-703	803-950	April 05, 1968	60
65-23-702	472-772	January 28, 1952	38
65-23-702	472-772	February 27, 1956	40
65-23-704	990-1200	March 11, 1953	91
65-23-704	990-1200	April 25, 1962	94
65-23-704	990-1200	April 05, 1968	85
65-23-804	1661-1676	June 08, 1939	47
65-23-804	1661-1676	June 10, 1939	268
65-23-804	1661-1676	December 22, 1953	312
65-23-805	1399-1414	June 10, 1954	328
65-23-805	1399-1414	May 12, 1965	362
65-24-110	591-1538	January 22, 1947	84
65-24-110	591-1538	April 19, 1961	88
65-24-110	591-1538	April 17, 1972	65
65-24-404	1307	July 12, 1963	122
65-24-404	1484	July 14, 1963	248
65-24-404	694-1120	August 20, 1963	47
65-24-404	694-1120	February 06, 1974	43
65-24-606	979-989	June 26, 1957	117
65-24-606	979-989	May 12, 1965	114
65-24-605	1303-1308	November 17, 1945	114

* See Exhibit III-2 for location of wells.

TABLE III-4
(cont.)
CHLORIDE CONCENTRATION OF VARIOUS WELLS (17,19,20)

Well Number	Depth of Producing Interval (ft)	Date	Chloride (mg/l)
65-24-605	1153-1158	November 17, 1945	1040
65-24-605	1126-1131	November 18, 1945	880
65-24-605	970-975	November 19, 1945	850
65-24-605	667-672	November 20, 1945	720
65-24-605	714-719	November 20, 1945	825
65-24-605	550-555	November 21, 1945	710
65-24-605	512-517	November 25, 1945	104
65-24-610	770	February 01, 1939	112
65-24-610	770	February 01, 1949	122
65-24-610	770	March 02, 1955	130
65-24-801	405-435	September 09, 1957	50
65-24-801	405-435	November 16, 1965	50
65-24-901	400-550	March 06, 1947	68
65-24-901	400-550	February 08, 1957	74
65-24-901	400-550	March 31, 1965	72
65-24-902	417-575	March 21, 1966	60
65-24-902	417-575	February 05, 1974	67
65-31-206	465-571	July 28, 1955	47
65-31-206	465-571	April 22, 1974	46
65-31-801	485-535	November 10, 1959	44
65-31-801	485-535	May 15, 1972	38
65-32-201	495-590	July 08, 1965	91
65-32-201	495-590	April 22, 1970	100
65-32-305	590	July 08, 1965	91
65-32-305	590	March 05, 1971	91
65-32-405	536-624	March 17, 1965	79
65-32-405	536-624	February 16, 1971	89
65-32-610	527	June 07, 1940	146
65-32-621	640-661	June 06, 1967	214
65-32-621	640-661	August 07, 1970	198
65-32-701	528-610	February 07, 1957	57
65-32-701	528-610	August 01, 1961	59
65-32-701	528-610	March 04, 1971	69
65-32-706	563	February 03, 1939	44
65-32-706	563	February 06, 1956	46
65-32-711	592-659	February 03, 1939	90
65-32-711	592-659	February 07, 1949	94

TABLE III-4
(cont.)
CHLORIDE CONCENTRATION OF VARIOUS WELLS (17,19,20)

Well Number	Depth of Producing Interval (ft)	Date	Chloride (mg/1)
65-32-711	592-659	March 18, 1960	102
65-32-711	592-659	February 17, 1971	100
65-32-716	568-590	May 04, 1954	68
65-32-716	568-590	May 04, 1964	69
65-32-716	568-590	May 05, 1974	63
65-32-902	520-575	August 11, 1961	134
65-32-902	520-575	May 21, 1974	160
65-39-503	598-618	December 08, 1966	178
65-39-503	598-618	December 09, 1966	368
65-40-102	310-781	May 11, 1956	207
65-40-214	550-571	August 19, 1964	85
65-40-401	647-767	May 01, 1953	220
65-40-401	647-767	July 19, 1963	285
65-40-401	647-767	April 25, 1973	310
65-40-401	647-767	November 14, 1974	240
65-40-407	638-658	December 29, 1966	98
65-40-407	728-748	December 30, 1966	373
65-40-503	640-763	May 01, 1953	212
65-40-503	640-763	May 10, 1963	210
65-40-503	640-763	May 09, 1974	190
65-40-616	770-790	July 19, 1963	445
65-40-616	770-790	May 16, 1968	445
65-40-701	677-773	May 10, 1960	322
65-40-701	677-773	April 07, 1970	390
65-40-703	699-761	May 01, 1953	252
65-40-703	699-761	May 12, 1964	268
65-40-703	699-761	November 11, 1973	280
65-40-704	656-767	May 01, 1953	280
65-40-704	656-767	May 12, 1964	265
65-40-704	656-767	May 10, 1972	290
65-40-706	661-775	March 24, 1958	360
65-40-706	661-775	May 14, 1968	378
65-40-706	661-775	May 20, 1971	380
65-40-802	636-776	May 01, 1953	220
65-40-802	636-776	May 10, 1963	222
65-40-802	636-776	April 25, 1973	210

wells are in the "Alta Loma Sands" and provide water for the City of Galveston. Since there was very little pumping before 1899, it is evident that saline water has been present in the lower part of the sand.

From 1940 to 1942, the City of Galveston was engaged in a test drilling program designed to determine the position and extent of salt water in the "Alta Loma Sands" in the Alta Loma area. It was found that in the area north of Alta Loma, the main sand body is relatively thin and contains water lower in chloride content, but even in this area a vertical chloride gradient within the sand body is apparent. Wide variations in chloride content were found laterally and vertically.(18)

The wells producing in the "Alta Loma Sands" in Galveston County, just below the south boundary of the Greater Houston 208 Planning Area, shows some increase in chloride concentrations from 1953 to 1971. The chlorides in the water now range between 600 ppm to 800 ppm in 1971 compared to only 400 ppm to 600 ppm in 1953. However, some wells show a decrease in chloride concentrations between these years, possibly due to pumping from a higher water elevation. The deterioration of water quality indicates the movement of the salt water encroachment past this point and into the Greater Houston 208 Planning Area.

Table III-4 shows the change of chloride concentration of various wells within the Greater Houston 208 Planning Area. See Exhibit III-2 for location. Wells in the far southern portion of the Planning Area between Dickinson and Algoa have had some increase in chloride concentration between 1959 and 1972, indicating some movement of saline waters. However, well data shows no increase in chlorides since 1966 and even some reduction of the concentration for some wells.

In Harris County, salt water intrusion does not appear to affect the water quality of wells. An Exxon pipeline company well (number 65-32-711) near the county line shows an increase from 90 ppm to 100 ppm in chloride concentration in its thirty-five year history. Since 1952, the well has maintained about the same chloride concentration. As can be seen in Table III-4, water quality from wells in Harris County is of low chloride concentrations and no significant impact is caused by the salt water intrusion such as that which seriously affects Galveston County.

Figure III-6 is a graph showing the change of chloride concentrations of wells during a thirty-year period. Beginning with well number 65-40-703 near the southern boundary of the

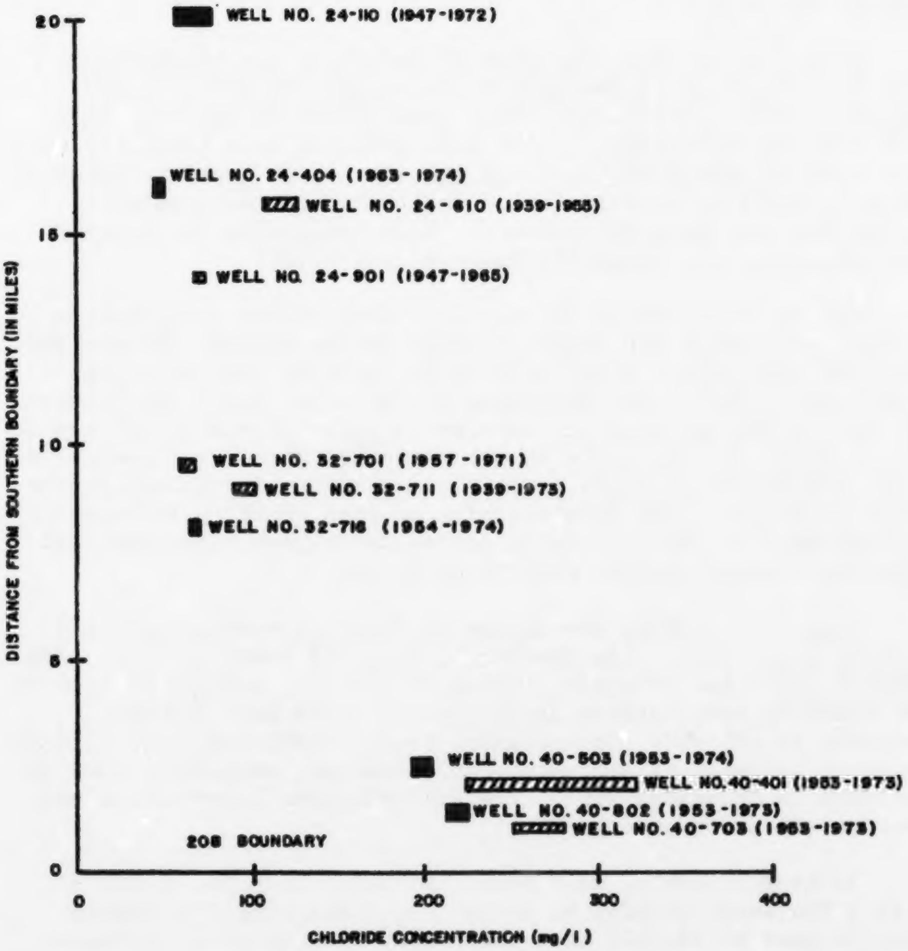

FIGURE III - 6

CHANGE IN CHLORIDE CONCENTRATION IN WELLS LOCATED BETWEEN LONGITUDE 95°00' 00" AND 95°07'30"

LEGEND	
■	DECREASE
▨	INCREASE

Greater Houston 208 Planning Area (bottom of the graph) and continuing northward, the graph indicates that:

1) Chloride concentrations are highest near the southern boundary;

2) These concentrations tend to decrease as one proceeds northward; and

3) No significant increases in chloride concentrations can be found in wells located in Harris County.

Modeling

An electric analog model was used to simulate the altitudes of the potentiometric surfaces of both aquifers in various plans of water development, as reported in "Analog-Model Studies of Groundwater Hydrology in the Houston District, Texas." In 1970, the Houston District used about 575 MGD of groundwater. According to the model, total withdrawals of about 1,000 MGD may be possible without seriously increasing salt water encroachment if the location of future wells are properly placed. It also noted that significantly large pumpage can continue in the Houston area and if fresh water would be recharged into the present cones of depression, reduction of salt water encroachment may be possible, even with the present rate of groundwater consumption. The report indicates that the salt water intrusion, even though a problem along the coast and in the industrialized sector of the area, can be reduced or held under control with proper water management techniques.(13)

Preliminary Assessment of Shipping Impact

Summary

Federal, commercial and recreational watercraft have been identified as sources of solid and liquid waste discharges in the Houston Ship Channel. The major portion of these solid and liquid waste discharges is generated by the sanitary system, ballast system, bilge system, oil spills, cargo oil tank cleaning system and the loading and discharging of dry bulk cargo vessels.

This section has identified and evaluated the polluting wastes from shipping activities, but no data was found that quantifies the amount of wastes on a daily or annual basis. A method to compute a daily waste generation matrix for any port facility is presented and could be used if sufficient data were available. Governmental regulations pertaining to wastes from shipping activities have set standards to control the quality of effluent and curtailed the quantity that can be discharged into traveled port areas. However, enforcement of these regulations were not evaluated due to the lack of substantial data.

The Houston Ship Channel is a dredged channel which serves as an access link for ocean-going vessels to the Port of Houston. The channel extends from the turning basin in Houston to Galveston Bay at Morgan's Point, a distance of about 25 miles. Besides its primary function as a commerce link, the channel provides large quantities of industrial cooling water and acts as a collector and transporter of large quantities of waste from the Houston area urban-industrial complex. It is the channel's use as a waste receiving stream that has produced the existing water quality problems that in turn have necessitated a waste load allocation.(21)

Personal Interviews

The following agencies were contacted for the purpose of collecting data and the inspection of existing techniques for the treatment and disposal of ships' wastes:

1) Port of Houston Authority

2) Galveston District Department of Customs

3) Houston District Department of Customs

4) U. S. Army Corps of Engineers

5) U. S. Coast Guard

6) Texas Water Quality Board (Austin and Deer Park offices)

7) Longshorman's Local 872.

It was found that the amount of information relating to ships' movement and ships' waste generation are very limited due to the following reasons:

1) None of the agencies mentioned above keep records as to the movement of private ships, barges and tugboats across the port or bay waters.

2) None of the agencies mentioned above keep records as to the amounts and characteristics of wastes generated by ships and unloaded in the port facilities.

3) None of the agencies mentioned above keep records as to the size of each ship and the number of crew members onboard.

Ship Data Collection

Based on the information obtained from personal interviews with the different agencies listed in the previous section, daily data on ship location, duration of stay and type of system operation, were found to be too incomplete to be of usefulness in this study. It was therefore decided to utilize the already compiled data by the U. S. Corps of Engineers and published in "Waterborne Commerce of the United States, Calendar Year 1974." Presented in Table III-5 is a summary of ships' movements in the Houston Ship Channel for calendar year 1974.(22)

Waste Categorization and Definition

Six major categories of waste have been considered covering the types of pollutants generated from shipping activities, these are defined as follows and further summarized in Table III-6:(23)

1) Sanitary Waste

Sanitary waste is wastewater carrying human waste or ground garbage.

2) Hotel Waste

Hotel waste is the liquid waste generated in ships' laundry, showers, galleys and scullery, exclusive of ground garbage.

3) Oily Waste

Oily waste is liquid waste containing oils in varying concentrations.

4) Industrial Waste

Industrial waste is liquid or solid waste of various types generated aboard ship by miscellaneous functions such as dispensary, photo lab, repair ships and maintenance operations.

5) Solid Waste

Solid waste is waste generated aboard ship that cannot be classified as liquid.

TABLE III-5

TRIPS AND DRAFTS OF VESSELS
HOUSTON SHIP CHANNEL
FOR CALENDAR YEAR 1974 (22)

HARBOR OR WATERWAY	INBOUND						OUTBOUND					
	Self Propelled Vessels			Non-Self Propelled Vessels			Self Propelled Vessels			Non-Self Propelled Vessels		
DRAFT (FEET)	Passenger and Dry Cargo	Tanker	Towboat or Tugboat	Dry Cargo	Tanker	TOTAL	Passenger and Dry Cargo	Tanker	Towboat or Tugboat	Dry Cargo	Tanker	TOTAL
39	5	65				70	25	107				132
38	4	72				76	18	104			3	125
37	7	70				77	14	39			2	55
36	25	46				71	31	47			6	84
35	28	26				54	47	79				126
34	29	35				64	53	92			1	146
33	41	38			1	80	80	70			3	153
32	35	77				112	101	71			20	192
31	50	46				96	103	52			1	156
30	62	55				117	150	45			1	196
29	80	51		1		132	116	43	1			160
28	99	58			3	160	121	53	3		1	178
27	94	53			1	148	119	51	1			171
26	125	62	2	8	3	200	135	87	4		2	228
25	141	52		3	3	199	158	87				245
24	144	107		43	1	295	166	108			2	276
23	192	79	1			272	177	50				227
22	191	89	1			281	165	82		2	11	260
21	204	125	18	29		376	143	58	20	1		222
20	213	129	3			345	182	108	1	1		292
19	184	55	2	1		242	158	36	1	3	1	199
18 and Less	886	190	9,354	8,542	10,706	29,678	580	120	9,345	8,619	10,667	29,331
TOTAL	2,839	1,580	9,381	8,627	10,718	33,145	2,842	1,589	9,376	8,626	10,721	33,154

TABLE III-6

TYPICAL SHIP WASTES (23)

Classification		Generation	
Category	**Type**	**Source**	**Description**
Sanitary	Sewage	Heads	Human Waste
		Grinders	Garbage
Hotel	Hotel	Laundry	Detergents
		Showers	Soaps
		Lavatories	Soaps
		Scullery	Washdown
Oily	Slop Oil	Hydro System	Slop Waste
		Machine Shop	Lubricants
		Diesel Gen.	Lubricants, Diesel Oil
		Vehicles	Gasoline, Oils
		Fuel Tanks	Discharge
Industrial	Shop Waste	Machine	Acids, Cutting Oils
		Print	Inks
		Paint	Paint, Thinners
		Carpentry	Oil, Paint
		Tailor	Bleach, Tint
		Hobby	Miscellaneous
	Maintenance	Boiler	Acids
		Batteries	Acids
		Electronic	Oils, Solvents
		Gun Emplement	Washdown
		Hospital Lab	Chemicals
		Photo Lab	Chemicals
		Repair Facil.	Chemicals
	Miscellaneous	Household	Acids, etc.
		Damage Cont.	Foam, Powder
		Fire Cont.	Foam
		Laundry	Solvents
Solid	Segregated	Paint Shop	Cans
		Recreation	Cans, Glass
		Galley	Cans, Glass
		Hospital	Cans, Glass
		Labs	Cans, Glass
	Unsegregated	Hydro. Sys.	Synthetics
		Machine Shop	Iron Filings
		Repairs	Miscellaneous
		Print Shop	Paper
		Vehicle Maint.	Rags, Iron
		Carpentry	Wood
		Tailor	Rags
		Hobby	Miscellaneous
		Commissary	Miscellaneous
		Recreation	Miscellaneous
		Galley	Miscellaneous
		Offices	Trash
		Hospital	Trash
		Labs	Trash
		Boiler	Firebrick
Air Pollution (Dusts)	Loading and unloading dry bulk cargo	Non-liquid bulk cargo vessels	Alumina
			Bauxite
			Cement
			Clay
			Coal
			Gypsium
			Limestone
			Salt
			Wheat

6) Air Pollution

Air pollution is the wastes generated by loading and discharging dry bulk cargo.

Daily Waste Generation Matrix

After extensive research, no publications were found as to the quantification of wastes generated by the different vessels, including passenger and dry cargos, tankers, barges, towboats and tugboats. The U. S. Department of the Navy has published several reports giving waste generation rates for individual naval vessels; however, it was not possible to establish any correlation factor to facilitate the determination of ships' waste generation rates for commerical watercraft.

The quantity of domestic waste per each vessel may be computed by multiplying the number of passengers and crew members times the quantities presented in Table III-7. The quantities of sanitary wastes for a port facility may be computed by using the following equation:(24)

$$\text{Daily Waste Load} = W_1 N_1 + W_2 N_2 + W_3 N_3 + \text{---} W_n N_n$$

Where: W_1 - Daily waste generation of ship type 1
W_2 - Daily waste generation of ship type 2
W_3 - Daily waste generation of ship type 3
W_n - Daily waste generation of ship type n
N_1 - Number of ships of ship type 1 in port per day
N_2 - Number of ships of ship type 2 in port per day
N_3 - Number of ships of ship type 3 in port per day
N_n - Number of ships of ship type n in port per day

Waste Parameters

Sanitary and Hotel Wastes. Basically there exists two sources of sanitary and hotel wastes which are:(24)

1) Human wastes including flushwater at the rate of 30 gpcd.

2) Human and domestic wastes at the rate of 30 gpcd.

Associated with the above two types, there are three alternative levels of effluent quality which are further summarized in Table III-7.

TABLE III-7

DEFINITION OF SOURCE AND QUALITY LEVELS (24)

	Level I	Level II	Level III
Waste Source	Human wastes (W C and urinals)	Human wastes (W C and urinals)	All domestic wastes (human, showers, laundry, lavatory, and galley)
Rate (gallons/capita/day)	30	30	30 (Human) 30 (Other domestic)
Quality			
BOD (mg/l)	600	600	400 (Total)
SS (mg/l)	800	800	470 (Total)
Effluent Quality			
BOD (mg/l)	50	50	50
SS (mg/l)	150	80	80
Coliform (MPN/100ml)	1,000	240	240

1) Level I

Sewage of human origin to be treated so that any discharge into restricted waters would meet the following minimum standards:

BOD_5	50 mg/l
Suspended solids	150 mg/l
Coliform count	1,000 MPN per 100 ml

2) Level II

Sewage of human origin to receive secondary treatment to produce an effluent quality meeting higher standards than those for Level I.

3) Level III

All domestic wastes to produce an effluent meeting higher standards than those for Level I. Domestic wastes include human waste, wash water, shower water, kitchen and laundry wastes.

The standard quality specified for Level I are based on the levels of treatment recommended by the U. S. Public Health Service for vessel construction.

Several trade associations and organizations including the National Association of State Boating Law Administrators, the American Boat and Yacht Council, Inc., and the Yacht Safety Bureau, testifying at the 1968 Senate hearings on Water craft Pollution Control recommended standards as outlined in Table III-7.

Oily Wastes.(25) Four major categories of oily wastes were considered:

1) Bilge volumes generated by ships in port.

2) Bilge volumes generated by arriving ships.

3) Volume of contaminated oil settling (COS) oily waste brought to port by arriving ships.

4) Volume of ballast water brought to port by arriving ships assuming a fuller ballasted condition.

Oily wastes generation rates may be expressed in the following formula:

$$V = N \frac{Pst\ (Rst) + Pc\ (Rc)}{100}$$

Where:

V = Volume of bilge water generated per day for a particular ship type
N = Number of ships per day of the ship type at port area
Pst = Percent of inport time the ship is in an auxiliary steaming mode
Rst = The generation rate of the ship type which is in auxiliary steaming status, in gallons per day
Pc = Percent of inport time the ship is in cold iron mode (all systems off)
Rc = The generation rate of the ship type while in cold iron mode, in gallons per day

Based on studies conducted on Navy ships, oil concentrations in bilge and ballast waters ranged between 1 mg/l to 960 mg/l while suspended solids ranged between 0 mg/l to 64 mg/l.

As to the accidental oil and other waste spills, according to Texas Water Quality Board Publication,(26) "Accidental spills of oil and hazardous materials present problems which do not lend themselves to classical water pollution abatement techniques. These shills cannot be seen, are not permitted, and generally far exceed allowable discharge limits. The Texas Water Quality Board has adopted a contingency plan which provides for spill response, prevention and enforcement."

Shipboard Industrial Wastes. No data are presently available assessing the quantities of wastes generated by shipping activities, it is further recommended that field investigations be conducted relating to this subject.

Solid Wastes. No data are presently available assessing the quantities of wastes generated by shipping activities, it is further recommended that field investigations be conducted relating to this subject.

Air Pollution. No data are presently available assessing the quantities of wastes generated by shipping activities, it is further recommended that field investigations be conducted relating to this subject.

Regulatory Requirements

There are basically three (3) sets of regulations or legislation that are considered adequate to cover the regulatory requirements of the ships' waste discharge.

Federal Water Pollution Control Act - Amendments of 1972. This Act, enacted in October of 1972, is directed toward ridding the waters of the United States of all pollution by 1985. It mandates preservation of all existing water quality standards as the minimum standard and has provision for the upgrading of standards where possible in may parts of the country as the rules and regulations for implementating the Act are prepared by the Environmental Protection Agency. As a practical matter, the impact of the legislation on the ships; wastes is to confirm the need for either an offland system capable of removing all ships' waste from ship to shore facilities without any discharge of pollutants to the surrounding waters or a system of shipboard treatment for all wastes aboard all ships.

Control of Waste from Watercraft. Board order 74-0521-4 approved May 21, 1974 pursuant to section 21.097 of the Texas Water Code, provides that any boat which has permanent sleeping quarters thereon and which is situated or operated on fresh waters of the State of Texas shall be equipped with an approved marine sanitation device.(26)

Ocean Dumping. The Texas Water Quality Board has an interest in the disposal of wastes at sea, especially where wastes originate in Texas. The Board is also concerned where the ocean dumping sites may be outside Texas' jurisdiction, because it is possible for wastes to return into the coastal waters of the State.(26)

It is the intent of the Board to continue coastal surveys to determine the severity of the ocean dumping problem and to identify particular areas of the coast which are more involved than others. Surveillance activities and sampling of containerized waste disposal ashore are conducted by the Board.

Preliminary Assessment of Agricultural Impact

Summary

The majority of agricultural runoff can be classified as the Planning Area's natural runoff. Timber stands north of Spring Creek and range lands throughout the agricultural sector can be described as typical of the vegetation cover before the arrival of man into the Planning Area. The croplands contributing additional sediment and nutrients above the natural runoff values are located predominantly in the west and northwest portion of the area. Some of this runoff drains into either Barker or Addicks Reservoirs, which allows some of the pollutants in the stream's flood waters to either be deposited, as in the case of sediment, or be reduced, as in the case of Biochemical Oxygen Demand. The remaining portion of that runoff is either in the Spring or Cypress Creek Watersheds. Preliminary investigation shows little detriment to water quality.

By utilizing both research performed in various parts of the country and data gathered from stream monitoring of agricultural runoff in the Greater Houston 208 Planning Area, the quantities of four (4) water quality parameters on a per acre basis was estimated. These values were then used to determine annual loadings to streams in each of the subcatchments containing agricultural lands. Water quality parameters used for this study included Biochemical Oxygen Demand, Total Suspended Solids, Nitrate Nitrogen, and Total Phosphates. These annual loadings for each parameter for each subcatchment are presented later in this section of this report.

Pesticide use in the agricultural sector could not be reliably estimated or determined on a subcatchment basis. However, pesticide use in the forested area of the agricultural land is practically non-existant and no effects of its employment, if any, can be found. Water quality data from U. S. Geological Survey monitoring stations on bayous downstream of agricultural lands show some pesticides in minute concentrations during Spring and Summer months, less in the Winter and Fall months. These same bayous normally have higher concentrations of the same chemicals when urban runoff is added downstream of the agricultural lands. This could mean that certain pesticides in streams are contributed more by urban, than by agricultural runoff, although no studies were found to substantiate this conclusion.

Very little confined animal production was found in the Greater Houston 208 Planning Area. These sources were of little magnitude and do not create significant, if any, detriment to water quality in the receiving streams.

Irrigation return flows can be essentially confined to rice production only. Studies performed by the Rice Center in Beaumont indicate that rice fertilizers, herbicides, and pesticides tested have negligible effects to receiving stream water quality if proper water management techniques are adhered to. Four of the insecticides and herbicides commonly employed in rice farming were evaluated and found to degrade at such a rapid rate that concentrations of these chemicals were not found after a short period of time after application.

Annual Loadings in Subcatchments

The four parameters employed to assess the water quality of agricultural runoff are nitrate nitrogen, total phosphates, BOD, and TSS. All four parameters were estimated in tons per year per subcatchment. In order to attempt to qualify and quantify the parameter loadings of the agricultural lands in the Greater Houston 208 Planning Area, aerial photographs and the Houston-Galveston Area Council (H-GAC) land use maps were used to differentiate between the areas used for agricultural purposes and all other land uses. The agricultural land was then divided into four major classifications:

1) Land with levees used predominantly for rice and soybean production;

2) Crop lands without levees used for production of soybeans, nursery products, truck farming products, and other commercially sold goods;

3) Forest and pastures; and

4) Range lands including those areas used for grazing for farm animals and those temporarily out of crop production.

These four agricultural uses were estimated as a percentage of each subcatchment involved. Difficulty arose in determining range lands used for agricultural purposes and those lands which are considered vacant and have no potential for agricultural deployment. In the fringes of urban development, aerial photographs, land use maps, and knowledge of the area were used to differentiate between the two uses. For this Chapter, vacant land is defined as land not being used for agricultural purposes and therefore has potential for urban development within the time frame of this study. It is assumed that this vacant land will never return to function as agricultural lands. Certain range lands may have essentially the same runoff factors as vacant land, but those loadings from vacant lands are included in the urban runoff computations in Chapter I so that doubling of loadings would not occur.

In estimating the future loadings in each subcatchment, it was assumed that even though the total amount of agricultural lands would decrease because of increased urban development as forecast in "Population and Land Use, July 1976" by H-GAC, the percentage of the four major classifications of land use in each subcatchment would remain essentially fixed.

TABLE III-8

LOADING FUNCTIONS

LAND USE CLASSIFICATION	Nitrate Nitrogen (lb/ac/yr)	Total Phosphates (lb/ac/yr)	BOD (lb/ac/yr)	TSS (tn/ac/yr)
Land in terraces used for crop production	.1 to .5	.1 to .5	6 to 10	.01 to .05
Land without terraces used for crop prod.	.1 to .5	.3 to .6	6 to 8	.2 to .4
Forest and/or Pasture	.1 to .2	.05 to .15	2 to 6	.008
Range or non-productive lands	.1 to .2	.04 to .10	2 to 6	.01

The loadings were computed using various factors for BOD, TSS, and Nutrients based on land use classification. These factors, which can be seen in Table III-8, remained constant for each of the planning years. These factors were based on data gathered on research performed throughout the country that dealt with annual loadings from agricultural lands. Most of the research employed dealt with nutrients and suspended solids. BOD loadings had extremely limited sources of data for agricultural runoff, excluding the research performed for confined animal production. These factors were calibrated for the Greater Houston 208 Planning Area by the use of the data accumulated by the U.S.G.S. monitoring stations located on streams draining predominantly agricultural lands. Be determining average concentrations of the parameters in the streams and knowing the total annual runoff and drainage area, one can obtain the annual average amount of nutrients, suspended solids, and BOD generated on a per acre basis; however, it should be noted that using this method does have inherent problems. The land in the particular drainage basin contains more than one type of land use; and, stream reduction of BOD, and the sedimentation of suspended solids will give less than the average loading factor that is actually contributed by an acre of land in the drainage basin. Also, other factors, such as the change of farming patterns (i.e., the increasing acreages devoted to soybean production in Harris County) and more agricultural lands held by investors rather than those engaged strictly in farming enterprises, will alter the loading rates on a per acre basis, especially in the future years.

Therefore by knowing the total acreage devoted to agricultural purposes, and determining the percentage of each agricultural land use in the subcatchments, and by applying the annual loading rates per acre for each parameter, total annual loads were calculated. An Example is as follows:

SAMPLE CALCUALTIONS

KNOWN VALUES:

Total acreage in subcatchment - 6,600
Total non-agricultural lands - 430
Total agricultural acreage - 6,170 (1975 only)

Percentage of:
  Crop land in terraces - 10%
  Crop land without terraces - 20%
  Forest and/or pasture - 30%
  Range lands - 40%

FIND TOTAL SUSPENDED SOLIDS FOR YEAR 1975:

Agricultural Land		Percent		Loading Function		Subtotal
6,170	x	.10	x	.03	=	18.5
6,170	x	.20	x	.3	=	370.2
6,170	x	.30	x	.008	=	14.8
6,170	x	.40	x	.01	=	24.7
		Total TSS per year per subcatchment				428.2 Tons

This type of computations was performed for each parameter for each year. Table III-9 gives all loadings for each planning year for each subcatchment that contains agricultural lands. Loadings for the various design storms could be normalized by the use of the annual loadings and pertinent runoff data. However, it should be noted that all factors are based on research giving

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT

YEAR 1975

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
101	.88	.88	23	330
102	.74	.76	17	840
103	.31	.30	8	330
104	1.26	1.15	31	1,090
105	3.99	3.74	98	3,280
106	2.04	1.92	51	1,690
107	.20	.11	6	30
108	.04	.02	1	10
109	.42	.22	13	60
201	.28	.20	9	150
301	.25	.20	7	180
302	1.78	1.59	45	1,590
303	.77	.55	22	370
304	.07	.05	2	30
305	.03	.02	1	10
306	.82	.68	22	600
307	.53	.40	15	410
308	.46	.35	13	570
309	.44	.33	14	250
310	.62	.42	18	310
311	.28	.15	9	40
401	.12	.06	4	20
402	.13	.07	4	20
501	.04	.02	1	10
502	.04	.02	1	10
503	.08	.05	2	40
504	.08	.05	2	40
505	.09	.06	3	40
506	.26	.20	7	200
507	.07	.05	2	50
508	.10	.06	3	20
509	.15	.12	4	110

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1975

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
510	.06	.03	2	10
515	.03	.02	1	30
525	.14	.09	4	50
708	.28	.15	9	50
801	1.20	1.09	33	510
802	1.08	.94	31	330
803	1.20	.91	37	180
804	.44	.23	14	70
901	.71	.58	19	510
902	.39	.25	11	200
903	.52	.33	16	180
904	1.03	.90	27	680
905	.15	.12	4	110
906	.27	.14	9	40
907	.56	.46	15	270
908	.30	.23	9	140
909	.25	.17	7	130
910	.56	.47	15	240
911	.60	.53	16	400
912	.15	.09	5	50
913	.04	.03	1	20
914	.33	.28	9	180
915	.54	.29	17	90
1001	.02	.01	1	2
1101	3.40	3.34	79	4,000
1102	1.10	1.15	24	1,400
1103	.26	.28	6	350
1104	2.13	2.30	45	2,980
1105	1.28	1.36	30	1,260
1106	2.33	2.43	54	2,380
1107	2.09	2.14	50	1,830

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1975

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1108	1.07	1.07	25	1,220
1109	1.01	1.01	24	1,190
1110	2.14	1.99	54	1,900
1111	1.19	1.15	29	1,200
1112	.25	.22	6	230
1113	1.03	.91	26	950
1114	.44	.34	13	210
1115	.85	.74	23	720
1116	.47	.39	12	340
1117	.60	.50	16	440
1118	.52	.34	16	170
1119	.25	.17	8	80
1120	.68	.64	17	590
1201	1.69	1.49	44	1,120
1202	2.10	1.76	56	1,460
1203	.59	.49	15	410
1301	.45	.40	12	300
1302	.29	.20	8	140
1401	.27	.14	8	40
1402	.48	.26	15	80
1403	.95	.51	30	150
1408	.06	.04	2	30
1409	.06	.04	2	30
1410	.17	.10	6	30
1411	.28	.18	8	90
1415	.52	.36	16	250
1601	.61	.52	16	250
1602	.27	.14	8	40
1603	.28	.16	8	40
1604	.51	.32	16	20
1605	.09	.05	3	20
1606	.21	.11	7	30
1607	.13	.07	4	20

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1975

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1801	.12	.09	4	60
1802	.11	.10	4	60
1810	.09	.08	3	50
1901	2.42	2.06	70	1,160
1902	2.25	1.91	64	1,070
1903	3.82	3.25	113	1,840
1904	3.52	2.99	102	1,670
1905	.81	.69	23	380
1906	.47	.42	13	290
1907	.56	.49	16	340
1908	.66	.58	18	400
1909	.57	.48	16	270
1910	.77	.64	22	370
1911	.49	.42	14	230
1912	.65	.58	17	470
1913	3.56	3.28	94	2,330
1914	.38	.35	10	250
1915	1.58	1.33	46	750
2001	.15	.08	5	30
2002	.04	.02	1	10
2003	.15	.08	5	30
2004	.27	.15	9	40
2005	.34	.19	11	50
2006	.08	.04	3	10
2007	.13	.07	4	20
2008	.42	.22	13	70
2009	.27	.14	9	40
2101	.37	.30	11	120
2102	.72	.45	23	100
2103	.32	.25	10	40
2104	.53	.40	17	70
2105	.07	.04	2	10
2106	.09	.05	3	10
2107	1.21	.99	37	380

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1975

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
2108	.59	.38	19	80
2109	.10	.07	3	20
2110	.14	.09	4	20
2111	.34	.19	11	50
2112	.92	.62	30	120
2201	1.92	1.69	51	1,270
2202	.13	.11	4	90
YEAR 1983				
101	.88	.88	23	330
102	.74	.76	17	840
103	.30	.29	7	300
104	1.25	1.14	30	1,080
105	3.97	3.72	95	3,270
106	2.01	1.90	50	1,660
107	.20	.11	6	30
108	.04	.02	1	10
109	.42	.22	13	60
201	.25	.18	7	130
301	.25	.20	7	180
302	1.78	1.59	45	1,590
303	.77	.55	22	370
304	.07	.05	2	10
305	.02	.01	1	10
306	.79	.67	21	550
307	.53	.40	15	410
308	.46	.35	13	570
309	.42	.31	12	240
310	.61	.41	17	300
311	.28	.15	9	40

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1983

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
401	.10	.05	4	20
402	.13	.07	4	20
501	.04	.02	1	10
502	.04	.02	1	10
503	.08	.05	2	40
504	.08	.05	2	40
505	.09	.06	3	40
506	.24	.18	6	180
507	.06	.04	2	40
508	.07	.04	2	10
509	.15	.12	4	110
510	.06	.03	2	10
515	.03	.02	1	30
525	.13	.08	4	50
708	.24	.13	8	40
801	1.20	1.09	33	510
802	1.08	.94	31	330
803	1.11	.84	34	160
804	.39	.21	12	60
901	.69	.57	18	500
902	.36	.23	10	180
903	.51	.32	15	170
904	1.03	.90	27	680
905	.14	.11	3	100
906	.26	.14	9	40
907	.56	.46	15	270
908	.28	.22	8	140
909	.21	.14	6	100
910	.56	.47	15	240
911	.60	.53	16	400
912	.12	.08	4	40
913	.04	.03	1	20
914	.33	.28	9	180
915	.54	.29	17	90

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1983

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1001	.02	.01	1	2
1101	3.35	3.29	77	3,920
1102	1.10	1.15	24	1,400
1103	.26	.28	6	350
1104	2.13	2.30	45	2,980
1105	1.28	1.36	30	1,260
1106	2.33	2.43	54	2,380
1107	2.09	2.14	50	1,830
1108	.93	.93	22	1,070
1109	1.01	1.01	24	1,190
1110	2.14	1.99	54	1,900
1111	1.19	1.15	29	1,200
1112	.25	.22	6	230
1113	1.01	.90	26	930
1114	.42	.32	12	200
1115	.83	.72	22	690
1116	.40	.32	10	270
1117	.56	.47	15	410
1118	.49	.31	15	160
1119	.24	.16	7	80
1120	.65	.61	16	560
1201	1.67	1.47	43	1,110
1202	2.07	1.74	55	1,440
1203	.59	.49	15	410
1301	.43	.38	12	290
1302	.24	.17	7	120
1401	.25	.13	8	40
1402	.46	.25	14	80
1403	.86	.46	27	140
1408	.06	.04	2	30
1409	.06	.04	2	30
1410	.16	.09	6	30
1411	.27	.18	8	90
1415	.47	.32	14	230

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1983

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1601	.61	.52	16	250
1602	.26	.13	8	40
1603	.27	.16	8	40
1604	.50	.32	16	20
1605	.08	.05	3	20
1606	.20	.11	7	30
1607	.13	.07	4	20
1801	.12	.09	4	60
1802	.10	.08	3	50
1810	.08	.07	2	40
1901	2.35	2.00	68	1,120
1902	2.23	1.90	64	1,070
1903	3.79	3.23	111	1,820
1904	3.47	2.95	100	1,650
1905	.81	.69	23	380
1906	.46	.42	13	290
1907	.56	.49	16	340
1908	.66	.58	18	400
1909	.56	.48	16	270
1910	.77	.64	22	370
1911	.49	.42	14	230
1912	.60	.54	16	440
1913	3.56	3.26	93	2,330
1914	.37	.34	10	240
1915	1.58	1.33	46	750
2001	.14	.07	5	30
2002	.03	.02	1	10
2003	.14	.08	5	20
2004	.27	.15	9	40
2005	.33	.19	11	50
2006	.08	.04	3	10
2007	.13	.07	4	20
2008	.37	.20	12	60
2009	.26	.13	9	40

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1983

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
2101	.36	.29	11	120
2102	.70	.44	22	100
2103	.29	.22	9	40
2104	.52	.39	17	70
2105	.07	.04	2	10
2106	.09	.05	3	10
2107	1.20	.98	37	380
2108	.59	.38	19	80
2109	.10	.07	3	20
2110	.14	.09	4	20
2111	.34	.19	11	50
2112	.91	.62	29	120
2201	1.88	1.66	49	1,250
2202	.11	.09	3	70

YEAR 1990

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
101	.88	.88	23	330
102	.74	.76	17	840
103	.29	.28	7	290
104	1.25	1.14	30	1,080
105	3.97	3.72	95	3,270
106	1.99	1.87	50	1,640
107	.20	.11	6	30
108	.04	.02	1	10
109	.42	.22	13	60
201	.21	.15	6	110
301	.25	.20	7	180
302	1.77	1.58	44	1,590
303	.77	.55	22	370
304	.07	.05	2	10
305	.02	.01	1	10
306	.77	.65	20	520

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1990

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
307	.53	.40	15	410
308	.46	.35	13	570
309	.40	.30	11	230
310	.61	.41	17	300
311	.28	.15	9	40
401	.09	.05	3	10
402	.13	.07	4	20
501	.04	.02	1	10
502	.04	.02	1	10
503	.08	.05	2	40
504	.08	.05	2	40
505	.08	.05	2	40
506	.22	.16	5	170
507	.06	.04	2	40
508	.07	.04	2	10
509	.15	.12	4	110
510	.06	.03	2	10
515	.03	.02	1	30
525	.13	.08	4	50
708	.22	.12	7	30
801	1.20	1.09	33	510
802	1.08	.94	31	330
803	1.07	.81	33	150
804	.38	.20	12	60
901	.68	.55	18	480
902	.31	.21	9	150
903	.50	.32	15	170
904	1.02	.89	27	680
905	.13	.11	3	90
906	.26	.14	8	40
907	.56	.46	15	270
908	.28	.21	8	140
909	.21	.14	6	100

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1990

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
910	.56	.47	15	240
911	.59	.52	16	390
912	.11	.08	4	40
913	.04	.03	1	20
914	.33	.28	9	180
915	.54	.29	17	90
1001	.02	.01	1	2
1101	3.33	3.27	77	3,900
1102	1.10	1.15	24	1,400
1103	.26	.28	6	350
1104	2.13	2.30	45	2,980
1105	1.28	1.36	30	1,260
1106	2.33	2.43	54	2,380
1107	2.09	2.14	50	1,830
1108	.77	.77	18	880
1109	1.01	1.01	24	1,190
1110	2.14	1.99	54	1,900
1111	1.19	1.15	29	1,200
1112	.25	.22	6	230
1113	1.01	.90	26	930
1114	.41	.31	11	190
1115	.81	.71	21	680
1116	.33	.27	9	240
1117	.54	.46	15	400
1118	.46	.30	14	150
1119	.24	.16	7	80
1120	.62	.60	16	550
1201	1.64	1.44	43	1,080
1202	2.06	1.73	54	1,430
1203	.59	.49	15	410
1301	.43	.38	12	290
1302	.24	.17	7	120

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1990

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1401	.24	.13	8	40
1402	.45	.25	14	80
1403	.83	.45	26	130
1408	.06	.04	2	30
1409	.06	.04	2	30
1410	.16	.09	5	20
1411	.24	.17	7	80
1415	.45	.31	14	220
1601	.61	.52	16	250
1602	.26	.13	8	40
1603	.27	.16	8	40
1604	.49	.31	16	70
1605	.08	.05	3	20
1606	.20	.11	6	30
1607	.13	.07	4	20
1801	.12	.09	4	60
1802	.09	.07	3	50
1810	.07	.06	2	30
1901	2.32	1.97	67	1,110
1902	2.22	1.89	64	1,070
1903	3.78	3.22	110	1,800
1904	3.43	2.91	99	1,630
1905	.81	.69	23	380
1906	.45	.41	12	280
1907	.56	.49	16	340
1908	.66	.58	18	400
1909	.56	.48	16	270
1910	.77	.64	22	370
1911	.49	.42	14	230
1912	.56	.50	15	410
1913	3.56	3.26	93	2,330
1914	.37	.34	10	240
1915	1.58	1.33	46	750

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1990

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
2001	.12	.07	4	20
2002	.03	.01	1	10
2003	.14	.08	5	20
2004	.27	.15	9	40
2005	.33	.18	11	50
2006	.08	.04	3	10
2007	.13	.07	4	20
2008	.33	.18	10	50
2009	.25	.13	9	40
2101	.36	.29	11	110
2102	.70	.44	22	100
2103	.28	.22	9	40
2104	.51	.39	17	70
2105	.07	.04	2	10
2106	.09	.05	3	10
2107	1.20	.98	37	380
2108	.59	.38	19	80
2109	.10	.07	3	20
2110	.13	.09	4	20
2111	.34	.19	11	50
2112	.90	.61	29	120
2201	1.88	1.66	49	1,250
2202	.09	.07	2	50

YEAR 1995

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
101	.88	.88	23	330
102	.74	.76	17	840
103	.29	.28	7	290
104	1.25	1.14	30	1,080
105	3.96	3.71	95	3,260
106	1.99	1.87	50	1,640
107	.20	.11	6	30
108	.04	.02	1	10
109	.42	.22	13	60

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT (Continued)

YEAR 1995

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
201	.17	.12	5	90
301	.25	.20	7	180
302	1.77	1.58	44	1,590
303	.77	.55	22	370
304	.07	.05	2	10
305	.00	.00	0	0
306	.76	.65	20	520
307	.53	.40	15	410
308	.46	.35	13	570
309	.39	.30	11	230
310	.61	.41	17	300
311	.28	.15	9	40
401	.08	.04	3	10
402	.13	.07	4	20
501	.04	.02	1	10
502	.04	.02	1	10
503	.08	.05	2	40
504	.08	.05	2	40
505	.08	.05	2	40
506	.22	.16	5	160
507	.06	.04	2	40
508	.07	.04	2	10
509	.15	.12	4	110
510	.06	.03	2	10
515	.03	.02	1	30
525	.13	.08	4	50
708	.19	.11	6	30
801	1.20	1.09	33	550
802	1.08	.94	31	330
803	1.06	.79	33	150
804	.38	.20	12	60

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1995

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
901	.67	.55	18	480
902	.25	.17	8	130
903	.50	.31	15	170
904	1.02	.89	27	680
905	.13	.11	3	90
906	.26	.14	8	40
907	.56	.46	15	270
908	.28	.21	8	130
909	.21	.14	6	100
910	.56	.47	15	240
911	.59	.52	16	390
912	.10	.07	3	40
913	.04	.03	1	20
914	.33	.28	9	180
915	.54	.29	17	90
1001	.02	.01	1	2
1101	3.32	3.26	76	3,880
1102	1.10	1.15	24	1,400
1103	.26	.28	6	350
1104	2.13	2.30	45	2,980
1105	1.28	1.36	30	1,260
1106	2.33	2.43	54	2,380
1107	2.09	2.14	50	1,830
1108	.52	.52	12	590
1109	1.01	1.01	24	1,190
1110	2.14	1.99	54	1,900
1111	1.19	1.15	29	1,200
1112	.25	.22	6	230
1113	1.01	.90	26	930
1114	.36	.25	10	180
1115	.81	.71	21	680
1116	.30	.25	8	220
1117	.53	.45	14	390
1118	.45	.29	14	150
1119	.24	.16	7	80

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1995

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1120	.60	.56	15	520
1201	1.62	1.42	42	1,070
1202	2.04	1.72	54	1,420
1203	.59	.49	15	210
1301	.43	.38	12	290
1302	.24	.17	7	120
1401	.23	.13	7	40
1402	.44	.24	14	70
1403	.81	.43	26	130
1408	.06	.04	2	30
1409	.06	.04	2	30
1410	.15	.09	5	20
1411	.24	.17	7	80
1415	.44	.31	13	220
1601	.61	.52	16	250
1602	.25	.13	8	40
1603	.27	.16	8	40
1604	.49	.31	15	70
1605	.08	.05	3	20
1606	.20	.11	6	30
1607	.13	.07	4	20
1801	.12	.09	4	60
1802	.08	.06	2	40
1810	.06	.06	2	30
1901	2.30	1.96	67	1,100
1902	2.22	1.89	64	1,070
1903	3.75	3.20	109	1,790
1904	3.40	2.89	98	1,620
1905	.81	.69	23	380
1906	.45	.41	12	280
1907	.56	.49	16	340

TABLE III-9

ANNUAL LOADINGS OF WATER QUALITY PARAMETERS BY SUBCATCHMENT
(Continued)

YEAR 1995

SUBCATCHMENT	Nitrate-Nitrogen (TNS/YR)	Total Phosphates (TNS/YR)	BOD (TNS/YR)	TSS (TNS/YR)
1908	.66	.58	18	400
1909	.56	.48	16	270
1910	.77	.64	22	370
1911	.49	.42	14	230
1912	.54	.48	14	390
1913	3.56	3.26	93	2,330
1914	.37	.34	10	240
1915	1.58	1.33	46	750
2001	.11	.07	4	20
2002	.03	.01	1	10
2003	.13	.07	4	20
2004	.27	.15	9	40
2005	.32	.17	10	50
2006	.07	.04	2	10
2007	.13	.07	4	20
2008	.27	.14	8	40
2009	.24	.13	8	40
2101	.35	.29	11	110
2102	.69	.44	22	100
2103	.26	.20	8	30
2104	.50	.38	17	70
2105	.07	.04	2	10
2106	.09	.05	3	10
2107	1.20	.98	37	380
2108	.59	.38	19	80
2109	.10	.07	3	20
2110	.13	.09	4	20
2111	.34	.19	11	50
2112	.89	.60	29	120
2201	1.88	1.66	49	1,250
2202	.06	.05	2	40

annual loadings and any values derived for design storms would be strictly academic.

Sediment Loss by Agricultural Activities

Sediment loss from agricultural lands in the Greater Houston 208 Planning Area was estimated by the Universal Soil Loss Equation and found to be low compared with other farm lands throughout the country. These estimates were made based on related conditions and assigned values that were calculated from various research studies in other parts of the state and nation. No studies were found to be available which measured the actual sediment loss for any agricultural lands in the Planning Area. However, some data was gathered from U. S. Geological Survey monitoring stations taken from streams in predominantly agricultural areas.(27,28,29, 30,31)

Erosion from agricultural lands can be either sheet, rill, gully, or channel erosion. The flat coastal lands that comprise the majority of land in the Planning Area shows very little signs of rill or gully erosion. Sheet erosion is negligible due to the flatness of the ground; therefore, channel erosion probably causes the greatest amount of sediment loss in some areas of the agricultural land. In the timber and heavily wooded portions of the Greater Houston 208 Planning Area, the slightly greater slope may cause some form of rill and gully erosion to occur. The vegetation and natural cover seen in virgin forests reduces sheet erosion to negligible amounts. Greatest sediment losses occur during times when this natural cover is partially removed, such as during logging opertion, construction and urban development.

Sediment Losses Measured

Soil from agricultural runoff has been studied in several parts of the country. As mentioned, no studies of any magnitude for this area were found, but a review of the available data for other areas gives some indication of the impact upon water quality. These measured quantities are employed to adjust the factors in the Universal Soil Loss Equation.

Research by Dornbush, Anderson, and Harms on agricultural lands in South Dakota resulted in the following conclusions:

> "Annual soil losses were much lower than anticipated. Soil losses ranged from less than 10 lb/acre/yr to a maximum of less than 1,000 lb/acre/yr. While runoff due to rainfall accounted for nearly all (93.7%) of the sediment losses, it accounted for only about one-half of the soluble nutrient species.

> Most of the sediment in runoff waters was from cultivated fields with relatively small amounts originating on areas in permanent grass. The bulk of the soil losses, as well as losses of those constituents associated with the soil, occurred during short duration, high intensity rain storms. Almost all the soil lost during the 2 year study can be attributed to approximately the 1/3 of the runoff which was caused by rainfall. The instantaneous concentration of soil in the rainfall was directly related to the flow rate."(32)

The lands studied were sandy clay loam soils with an average slope of about four (4%) percent. The plots studied include cropland, grasslands and pasture ranging in size from 7.18 acres to 18.68 acres.

Sediment from some larger watersheds were measured by McCarl (33) and Dragoun and Miller.(34) An annual load of about 1 ton/acre was received from a 173 acre tract under cultivation.(33) A 481 acre watershed being farmed by conventional methods was compared with a 411 acre watershed on which improved farming practices such as terraces and grassed waterways were used. About 75% of the unimproved acreage was cultivated, while 60% of the improved land was cultivated.(34) Over a four year period, the sediment yield from the unimproved area was 8.4 ton/acre while the sediment yield from the improved field was 4.5 ton/acre. Runoff from the unimproved land averaged 3.9 in/yr while the average runoff from the improved acreage was 2.9 in/yr.(34)

Table III-10 gives some of the variations of sediment yield as measured throughout the United States.(35)

Impact to the Entire Greater Houston 208 Planning Area

Sediment from runoff is generally recognized as the greatest single pollutant from nonpoint sources. Soil erosion, however, is a natural process by which the production and distribution of sediments occur throughout the earth's surface to continually reshape the land form. Sediment will occur naturally in any stream and, when in amounts not exceeding those occuring in nature, will not do harm to aquatic life or alter the "natural order of events." Sediment can reduce the quality and the recreational and consumptive use of water. Sedimentation will occur at lakes (manmade or natural) with even small concentrations of suspended solids in the stream. Sediment will also contribute to the carrying of other water pollutants, such as nutrients and pesticides, as explained later in this section.

Storm events and the antecedent conditions existing before the storm play a significant role in the amount of sediment that

TABLE III-10

LONG-TERM SEDIMENT YIELDS FOR SELECTED WATERSHEDS IN U.S. (38)

Location	Drainage area, in square miles	Land Use, as a percentage			Average Annual Quantities		
(1)	(2)	Cropland (3)	Pasture—idle (4)	Forest (5)	Rainfall, in inches (6)	Runoff, in inches (7)	Sediment, in tons per square mile (8)
North Fork Clear Creek near Blackhawk, Colo.	56.8	—	10	90	24	3.8	340
Honey Creek near Russell, Iowa	13.2[a]	50	40	10	34	6.2	450
Mule Creek near Malvern, Iowa	10.6[a]	80	15	5	30	4.9	3,100
Plum Creek near Waterford, Ky.	31.9	50	25	25	50	15	1,100
Cuffawa Creek near Holly Springs, Miss.	31.3	25	60	15	52	10	4,200
Pigeon Roost Creek near Byhalia, Miss.	117.0	20	55	25	52	14	2,700
East Fork Big Creek near Bethany, Mo.	95.0	55	35	10	34	6.7	1,300
Mississippi River at St. Louis, Mo.	701,000	40	35	20	23 (15–40)	1.5	260
Dry Creek near Curtis, Nebr.	20.0	45	55	—	20	1.4	6,500
Stony Brook at Princeton, N.J.	44.5	35	15	25	45	22	140
East Fork Deep River near High Point, N.C.	13.9	30	15	45	44	22	1,000
Todd Fork Little Miami River near Roachester, Ohio	219.0	65	20	15	44	17	900
North Fork Little Miami River near Pitchin, Ohio	29.1	80	15	5	40	10	70
Bixler Run near Loysville, Pa.	15.0	25	10	60	42	16	93
Elm Fork Trinity River near Muenster, Texas	46.0	19	81	—	35	6.4	43

[a] A dam-building program affected about 40% of the watershed area during the streamflow-sampling period.

is eroded from the surface and the stream's channels. Williams (36,37,38,39) calculated that a watershed near Riesel, Texas would yield .06 ton/acre for a three month frequency storm but .45 ton/acre for a five year frequency storm and 1.09 ton/acre for a 100 year frequency storm based on a modified Universal Soil Loss Equation. However, during high intensity storms, runoff and therefore the sediment carrying capacity of a stream is high and the only adverse impact to water quality is strictly temporary with damage being limited to deposition of sediment in areas such as lakes. During major storm, gully and channel erosion contribute the majority of the soil loss and not surface runoff; therefore, agricultural lands are not the main culprits.

Increasing amounts of erosion due to the lack of conservation practices can and does occur in the fringes of urban development. With the increasing cost of land, the farmer knows that he has the eventual option to either continue farming or to sell out to land developers or land speculators. With the eventual option of selling the land for purposes other than farming, the farmer or rancher may tend to reduce his conservation practices, thus increasing soil losses.

The agricultural lands of the Greater Houston 208 Planning Area can be divided into three major basin studies. Those draining into the Buffalo Bayou Reservoirs, those draining eventually into Lake Houston, and those draining into tributaries that lead directly into a bay.

The drainage basins of Addicks and Barker Reservoirs consist of 267 square miles, consisting mostly of range, rice farming, and soybean production with increasing amounts of urban development.

There is one U. S. Geological Survey monitoring station that tabulates water quality data from this area. This is station number 08073500, located on Buffalo Bayou at the Dairy-Ashford Road crossing. Table III-11 gives comparisons of the Total Nonfilterable Residue, Fecal Coliform, and Flow at various periods of time and also compares these values with data gathered downstream on Buffalo Bayou in predominately urban areas.

A review of Table III-11 indicates that there is no correlation between Total Nonfilterable Residue and Flow or between Total Nonfilterable Residue and time of year. Problems arise in trying to use this data to project the water quality parameters for the agricultural runoff in this area. Two factors come into play. First, the Addicks and Barkers Reservoirs disrupt the flow of the tributaries during flood stages and some of the solids will settle out above the dam. No studies were found showing the percent of solids that settle out. Second, below the two dams

TABLE III-11

COMPARISON OF DATA FROM USGS STATIONS OF BUFFALO BAYOU (27,28,29,30,31)

Date	Fecal Coliform*			Total Non-filterable Residue**			Flow (cfs)			NH_3N**		
	7350	7370	7400	7350	7370	7400	7350	7370	7400	7350	7370	7400
5/09/72	1,200	400	660,000	--	--	342	420	440	485	.28	.35	.51
10/10/72	180	1,200	6,800	73	8.6	24	135	145	162	.10	.49	1.2
1/02/73	11,000	76	140,000	268	216	216	143	191	270	.09	.60	1.7
2/20/73	13,000	780	21,000	234	278	300	863	895	856	.11	.19	.38
3/12/73	3,900	50,000	69,000	212	80	48	37	57	75	.75	5.5	3.8
4/17/73	8,300	5,800	12,000	422	376	328	1,100	1,530	3,170	.20	.18	.23
5/14/73	14,000	2,000	52,000	387	261	380	86	150	171	.63	1.90	.96
6/14/73	720	2,000	40,000	130	90	318	1,340	2,560	4,600	.07	.19	.46
7/24/73	390	550	2,700	189	115	145	122	205	156	.18	.6	.4
11/12/73	1	1	390	289	261	221	100	161	268	.44	1.9	.3
1/07/74	6,700	1,100	59,000	202	195	186	259	280	331	.29	.56	1.2
2/04/74	780	110	8,700	216	174	216	238	402	501	.15	.28	.52
3/05/74	31,000	380	3,000	57	174	37	14	42	49	1.1	3.5	1.2
3/19/74	1,400	19,000	73,000	177	222	364	291	343	294	.45	.6	1.2
3/25/74	35,000	950	48	529	338	273	201	320	559	.76	.64	--
4/15/74	20,000	1,500	9,300	99	137	88	160	187	185	.80	1.9	1.13
5/08/74	28,000	1,100	200,000	246	115	45	33	52	72	.67	4.2	2.2
6/12/74	8,000	1,100	8,000	163	31	22	30	59	60	2.5	3.6	2.0
7/10/74	7,300	420	14,000	136	68	41	45	71	77	.45	1.3	1.9
9/23/74	2,700	400	1,800	12	57	113	1,520	1,290	1,410	.22	.32	.42
10/07/74	3,600	140	2,800	116	69	70	110	230	180	.37	1.2	.68
12/03/74	430	5,000	2,400	103	105	109	280	380	380	.12	.39	.71
4/07/75	720	6,900	--	99	29	--	18	28	44	.11	8.5	--
4/16/75	--	--	50,000	--	--	464	--	--	420	--	--	.65
6/02/75	41,000	9,700	--	78	136	--	1,950	1,800	1,790	.13	.15	--
8/06/75	--	--	720,000	--	--	128	--	--	235	--	--	.14
8/12/75	170	190	--	57	83	--	600	720	785	.08	/08	--

* MPN/100ml ** mg/1

TABLE III-11
(Continued)
COMPARISON OF DATA FROM USGS STATIONS ON BUFFALO BAYOU (27,28,29,30,31)

Date	Dieldrin (ug/1)			Lindane (ug/1)			Diazion (ug/1)			Chlordane (ug/1)		
	7350	7370	7400	7350	7370	7400	7350	7370	7400	7350	7370	7400
5/09/72	.01	.02	.02	.06	.00	.00	.00	.02	--	.00	.00	.10
1/02/73	.01	.01	.06	.00	.00	.06	.00	.04	.18	.00	.00	.10
3/12/73	.02	.02	.01	.00	.00	.00	.02	.11	.04	.00	.00	.00
4/17/73	--	--	.03	--	--	.02	--	--	.07	--	--	.10
5/14/73	.01	.03	.04	.00	.00	.02	.01	.12	.09	.00	.10	.10
6/14/73	.02	.01	.06	.00	.00	.09	.01	.01	.33	.00	.00	.40
11/12/73	.02	--	.01	.00	--	.00	.17	--	.09	.10	--	.00
1/07/74	--	.02	--	--	.00	--	--	.01	--	--	.10	--
2/04/74	.00	.00	.01	.00	.00	.01	.01	.00	.02	.00	.00	.00
3/25/74	--	--	.04	--	--	.00	--	--	.57	--	--	.30
4/15/74	--	--	.02	--	--	.01	--	--	.18	--	--	.20
5/08/74	.02	.02	.03	.00	.02	.04	.01	.44	.17	.00	.00	.20
6/12/74	--	.02	--	--	.07	--	--	.43	--	--	.00	--
10/07/74	.01	.01	.01	.00	.01	.02	.01	.06	.03	.00	.00	.00
12/03/74	.00	.00	.00	.00	.00	.00	.00	.01	.05	.00	.00	.00
4/07/75	.01	.01	--	.04	.01	--	.01	.03	--	.10	.10	--
4/16/75	--	--	.04	--	--	.00	--	--	.05	--	--	.00
8/06/75	--	--	.01	--	--	.03	--	--	.17	--	--	.00
8/12/75	.00	.00	--	.00	.00	--	.00	.04	--	.00	.00	--

Note: 7350 - U.S.G.S. Station No. 08073500 - Buffalo Bayou @ Dairy-Ashford Street.
7370 - U.S.G.S. Station No. 08073700 - Buffalo Bayou @ Piney-Point Drive.
7400 - U.S.G.S. Station No. 08074000 - Buffalo Bayou @ Waugh Drive

and upstream from the monitoring station, urban development is present. In 1971, about 1.1 square miles of land was devoted to urban uses; in 1975, approximately 2.1 square miles of land had urban development, denoting construction activity throughout the entire period of monitoring. Because of these two variables, use of the measured water parameters must not be taken as typical for agricultural runoff in the Greater Houston 208 Planning Area. However, general analysis shows that urban runoff contribution after the monitoring station at Dairy-Ashford will reduce the Total Nonfilterable Residue concentration because of settling and dilution effects. No correlation between Total Nonfilterable Residue and Fecal Coliform was found. If the average Total Nonfilterable Residue Concentration (189 mg/l) measured at the monitoring station at Dairy-Ashford Road was compared with total runoff and drainage area, a distribution of 0.16 tons/acre/yr sediment loss would have occurred.

The sediment in the agricultural waters that drain into the two reservoirs pose no serious problem due to the nature of the flood control projects. Because these reservoirs are for flood control only, very little water is kept in the reservoirs so that water quality and detrimental affects on water use is practically nonexistent. Sedimentation has not impaired the function of these flood control reservoirs.

The agricultural lands draining into Lake Houston can be divided into two classes:

1) Lands with slightly hilly terrain with heavy stands of native trees

2) Flat prairie land with rice and soybeans being the dominant cash crop

Some sediment from these agricultural lands are being deposited in Lake Houston, and the sedimentation problem at Lake Houston has been noted to be acute.

Three U. S. Geological Survey monitoring stations are located in this drainage area and water quality data from these stations was employed for comparison and evaluation. The monitoring station numbered 080684500, located on Panther Branch near Spring, shows a Total Nonfilterable Residue concentration ranging from 16 to 622 mg/l. However, large increases of the concentration occured during parts of 1973 and 1974 when urban development was taking place. Otherwise, lesser concentrations of around 50 mg/l were being recorded, which is similar in concentration to measurements in monitoring station number 08068000, located on the North Fork San Jacinto River near Conroe, Texas. Based on this concentration and the total runoff quantity for the drainage area, total sediment yield is less than .03 ton/acre/yr for acreages containing large percentages of forest. In attempting to correlate solids with flow, the only determination that can be stated at the present time is that solids concentrations increase with flow rate, which is a standard condition. No correlation was found between Total Nonfilterable Residue and nutrients or the Fecal Coliform count.

The U. S. Geological Survey monitoring stations give water quality data for two points along Cypress Creek, which drains both flat prairie farm land and hilly timber lands. Table III-12 shows a comparison of the two stations. Increases in the concentrations of Total Nonfilterable Residue usually occurs at the downstream station on Cypress Creek. This occurrence is probably due to the construction activity and urban development between the two stations. Monitoring station number 08069200 near Humble with a drainage area of 319 square miles has approximately six percent of its area in urban related uses compared to about one percent for monitoring station number 08068750, located near Cypress. The upstream station shows an average of 137 mg/1 of Total Nonfilterable Residue over a four year period, which can be related to a sediment yield rate of less than 0.1 ton/acre/year.

The agricultural lands that are in sub-basins with outflow directly into the bays are located in the southeast and east portions of the Greater Houston 208 Planning Area. Less than twenty square miles of land used for agricultural purposes drains into the Clear Creek and Dickinson Bayou watersheds. Much of the land in this area is either in the process of urban development or considered vacant land awaiting urban development. If current trends continue, it is expected that the majority of soil losses will occur in areas of urban development and not in agricultural lands.

Nutrients from Agricultural Lands

In all, sixteen elements are known to be necessary for the growth of all plants. The air and water supply the carbon, hydrogen, and oxygen and the soil provides nitrogen, potassium, and calcium that are required in relatively large amounts. The remaining nutrients provided by the soil are phosphorus, magnesium, sulfur, manganese, boron, iron, zinc, copper, molybdenum, and chlorine. However, nitrogen and phosphorus are of most concern with respect to water quality.

Nitrogen is required in relatively large amounts and can be found in various forms in the soil. It moves from the soil to the streams by leaching through the soil or through erosion.

TABLE III-12

COMPARISION OF DATA FROM U.S.G.S. STATIONS ON CYPRESS CREEK (27,28,29,30,31)

Date	Total Nonfilterable Residue (mg/1)		Flow (cfs)		NH_3N (mg/1)	
	806875	806920	806875	806920	806875	806920
12/04/70	38	--	2.0	--	.14	--
2/19/71	148	19	0.18	2.2	.15	.06
6/17/71	84	156	0.74	2.9	.05	.06
8/19/71	52	222	1.4	8.3	.07	.19
12/20/71	222	199	27.0	44.0	.05	.24
2/07/72	175	247	20.0	38.0	.20	.32
6/08/72	128	56	19.0	24.0	.15	.18
10/27/72	75	400	26.0	85.0	.05	.19
2/05/73	178	148	12.0	30.0	.11	.37
4/26/73	293	380	95.0	340.0	.41	.34
8/30/73	160	561	40.0	72.0	.05	.23
11/01/73	218	236	260.0	--	.15	.21
2/15/74	229	122	6.7	29.0	.14	.75
5/02/74	141	52	1.6	9.1	.27	.39
10/21/74	43	90	7.9	24.0	.07	.21
3/20/75	952	812	136.0	--	.12	.22
5/23/75	90	95	--	13.0	.01	.08
9/24/75	69	84	6.6	15.0	.05	.39

Precipitation-borne nitrogen occurs in nature and it is estimated that nitrogen from this source is a significant part of the instream burden of the available forms of nitrogen.

Phosphorus can also take inorganic or organic forms and can be transported either by erosion or leaching. However, because phosphate absorbs strongly on soil particles, erosion is the primary mode of transport versus leaching, which is the main movement of available nitrogen. Precipitation-borne phosphorus has not been as an important source of nonpoint contribution to receiving streams.

It is important to remember when discussing the impact of nutrients on the eutrophication of lakes and streams that total nitrogen cannot be accepted as a true measure of pollution load. In order to be available to plant life, nitrogen must be "fixed" by combining with other elements in order for plants to be able to use the nutrient. This fixation occurs mainly through microbial action and the amount of "available nitrogen" is the most important term and amount. The available nitrogen will vary widely in soils depending on soil characteristics, degree of mineralization, and organic matter content.

Nutrient Losses from Agricultural Lands

Various investigations have evaluated the nutrient contributions from rural areas. These data are summarized in Table III-13. Kilmer (40) cited several authors who claim that nutrient losses from forest lands are insignificant and that nitrogen losses by leaching are also negligible from actively growing grassland. These two land use groups represented approximately 70 percent of the agricultural lands in Harris County in 1967.(41) It is estimated that this percentage has remained about the same since 1967 within the Greater Houston 208 Planning Area.(41)

The measured quantities of nitrogen and phosphorus reported by the various investigators exemplify the problem of estimating the amount of nutrients going into streams from agricultural lands. A good illustration is irrigated fields where the range for nitrogen is from 2.5 to 24.0 pounds per acre per year and the range for phosphorus discharge varies from .07 to 3.9 pounds per acre per year.

Methods for quantifying movement of nutrients in agricultural systems are still in the research stage. "Methods which are suitable for general use oversimplify the problem, must be used with descretion, and may be quite inadequate in certain cases. In particular, it is not presently possible to describe leaching processes for soluble forms of nitrogen."(55) Another specific

TABLE III-13
NUTRIENTS IN RURAL RUNOFF

Land Use	Stream Flow	or Surface Runoff	Nitrogen, lb/acre/yr	Phosphorus, lb/acre/yr	Remarks	Reference
Forest and Grazing Area	X		0.65 NO_3-N 0.90 Total N	0.33 Total P	Little cultivated land, Data extrapolated from 2 months sampling	42
Farmland	X		7.0 Total N	0.4 Total P	General farming conditions	43
Forested	X		1.3-3.0 Total N	0.3-0.8 Total P	Some logging and road construction	44
Diversified Farming		X	2.5-24.0 Total N	0.9-3.9 Total P	Irrigation return flows	44
Farmland	X		-	0-15 Ortho plus Hydrolyzable P_2O_5, as P	Heavily cultivated land. Data extrapolated from 6 summer months	45
Research Plots		X	3.1-6.4 Total N	0.03-0.21 Total	Natural conditions, small plots	46
Farmland		X	8.4 Total N	0.07 Total P	173 acre cultivated site in corn and oats	33
Research Plots and Orchard		X	0.8-237 Total N	0.36-9.0 Total P	Natural conditions, 1.5 acre plots, 5 acre orchard	47

TABLE III-13

NUTRIENTS IN RURAL RUNOFF

(Continued)

Land Use	Stream Flow	or Surface Runoff	Nitrogen, lb/acre/yr	Phosphorus, lb/acre/yr	Remarks	Reference
Farmland	X		7.35 NO_3-N	0.05 Ortho and Poly PO_4	No significant point discharges	48
Farmland	X		3.8 Total N	0.24 Total P	20% forest, 80% crop land and pasture	49
Rangeland	X		0.56 NO_3-N	0.021 Soluble P 0.067 Total P	Primarily grazing, no chemicals added	50
Farmland and Pasture		X	3.6 Total N	1.1 Total P	Higher than normal runoff, frozen sample storage	51
Farmland and Pasture	X		4.0 Total N	0.2 Total P	Mostly pasture, 6 mo. data, frozen sample storage	52
Irrigated Field			3.1 Total N	0.07 Total P	Subsurface drainage, no fertilizer applied	53
Research Plots		X	3.9 Total N	1.2 Total P	Small control plots with no applied manure, frozen sample storage	54
Forest			.19 Total N	.01 Total P	No fertilizer	40

problem in evaluating the movement of nutrients in agricultural lands in the Greater Houston 208 Planning Area is the diversified uses of agricultural lands in the various watersheds tributary to the major bayous and creeks. In the case of croplands, seasonal variations of nitrogen content in the soil occurs because of the application fertilizer. A review of the loading of nitrogen and phosphorus in streams as a function of nutrient concentration in the soil, sediment loading, and a nutrient enrichment factor was undertaken but eventually not employed due to lack of sufficient research data and unproven reliability. Estimated values of nutrient loadings produced a range of probable values up to 1,000 percent.(55) This low degree of accuracy does not justify the estimated values without some form of correlation to existing conditions.

Impact of Nutrients from Agricultural Lands. Nitrogen in its various oxidation states and at very high levels may be harmful to aquatic and terrestrial animals. Fish kills may occur if high amounts of ammonia are present in the water, and abortions in cattle and sheep have occurred from ingestion of high nitrate water. However, the major problem of nutrients is not fish kills (which occur rarely and not from agricultural practices) but the over production of aquatic vegetation. The more abundant the nutrient supply, generally the more dense the vegetation, provided other environmental factors are favorable. These growths may be bacteria, aquatic fungi, phytoplankton, filamentous algae, submersed plants, emersed plants, or floating plants. Limited concentration of algae presents no serious problems but over production causes eventual suppression of healthy aquatic plant growth, thus removing a food source for fish, production of undesirable tastes and odors in drinking water, the restriction of swimming, problems in aesthetics, and oxygen depletion due to the decaying algae. Excessive growth of aquatic plants may provide a suitable habitat for breeding of insect pests, may interfere with navigation, reduces drainage capacity, and reduces total fish production in infested water.

It should be noted that factors such as the amount of sunlight, depth of lake, surface area of lake, minor nutrients in water, type of water, characteristics of bottom soil, turbidity, temperature; and, most importantly, the concentration of nitrogen and phosphorus effect the growth of aquatic plants. The concentration of nitrogen and phosphorus for optimum growth of organisms according to studies by Chu, was nitrate nitrogen concentrations from 0.9 to 3.5 mg/l and phosphorus concentrations from 0.09 to 1.8 mg/l, while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l downward and in phosphorus concentrations from 0.009 mg/l downward.(56) Muller concluded that excessive growths of plants and algae in polluted waters can be avoided if the concentration of nitrate nitrogen is kept below about 0.3 mg/l and the concentration of total nitrogen is not allowed to rise much above 0.6 mg/l.(57)

The estimated quantities of nutrients discharged into streams from the various watersheds of the Greater Houston 208 Planning Area can be seen in Table III-9. Using research data accumulated by Kilmer (40) for forest areas, the average concentration of nitrogen and phosphorus in runoff from this land use was estimated to be about 0.1 mg/l and .01 mg/l, respectively. These values were determined by computing the amount of nutrients discharged from the watershed and dividing by the actual measured runoff from a stream gaging station. These concentrations are extremely small and do not jeopardize the water quality of the receiving streams or lakes. Estimates of loadings from range land and cropland that ultimately flows into the Addicks and Barker Reservoirs were made by converting the concentration of the nutrients in the runoff to annual functions per acre.

U. S. Geological Survey monitoring stations give data concerning the discharge and the concentration of the nitrogen and phosphorus in the receiving streams. Station 08073500 and station 08068750 show values from a predominantly agricultural area. Average phosphorus concentrations during the past five years is approximately .36 mg/l and the average nitrate nitrogen concentration is .51 mg/l for station 080673500 and .19 mg/l and .25 mg/l for station 08068750. Both are in concentrations high enough to cause algae production in streams and lakes. However, monitoring stations in urban areas downstream of these stations show much greater concentrations, concluding that urban areas contribute significantly more to the nutrient concentrations than does agricultural areas. A typical example can be readily seen in Table III-11 where the concentration of NH_3N increases as more urban drainage is added to the receiving stream. The monitoring station on the West Fork of the San Jacinto River (station 08068000), which drains predominantly forest areas located outside of the area but ultimately drains into the Planning Area, has an average concentration of phosphorus of .11 mg/l. From these tables, it can be seen that agricultural regions show significantly smaller contributions to the nutrient loading of streams compared to urban areas.

The nutrients in the streams of the Greater Houston 208 Planning Area cause some overgrowth of aquatic plants, especially in lakes and other standing waters. However, Addicks and Barker Reservoirs, which drain agricultural lands, are used for flood protection only and do not contain significant amounts of water except during floods, thus any algae production in the two reservoirs causes relatively no damage to wildlife nor odor or taste problems.

The other major reservoir in the Planning Area is Lake Houston. The concentration of nitrate nitrogen in Lake Houston near the intake from 0.2 mg/l to 2.2 mg/l. Total phosphorus ranges from 0.01 mg/l to 3.2 mg/l as measured near the intake. The lake receives both agricultural and urban runoff with urban development continuing to increase in the drainage area. Much of the agricultural area is heavily forested but waters from Spring Creek also contain runoff from various farming activities such as row crops, vegetable production, and rice irrigation waters. At present, there is relatively little algae problem in the lake according to lab personnel from Lake Houston. There are sufficient nutrients in the water to cause algae production; however, factors such as sunlight, turbidity, and temperature limit this growth.

No significant problems from aquatic growth occur in the streams in the agricultural areas. Most of these streams start in the agricultural sector of the Planning Area and flow into urban areas, where it has been shown that concentrations of nutrients increase at a significant rate. The nutrient loading from the agricultural lands are not of relative importance when compared to the point and nonpoint sources from urban areas.

Pesticides Impact from Agricultural Lands

Characteristics. The three major types of pesticides are the insecticides, for the control of insects; herbicides, for the control of unwanted plants; and fungicides, for the control of fungus and bacteria. Other types include nematocides, fumigants, mitcides, defoliants, desiccants, growth regulators, and rodenticides. Tables III-14 through III-16 shows nationwide use of the more commonly used pesticides along with certain properties that relate to pollution impact. The asterisks next to the name denotes suggested use by the Texas Agricultural Extension Service for crops grown in the Greater Houston 208 Planning Area.

Pesticides can be applied either as liquids or dry materials. Nationally, liquid sprays accounted for three-fourths of all pesticides used by farmers in 1966, and for 95 percent or more of the farmer's pesticide expenditures for wheat, rice, other small grains, sugar beets, alfalfa and other hay, pasture and rangeland, citrus, apples, and other deciduous fruit.(59) Seasonally, pesticide applications may be spread over a large part of the year, but the major share is applied in late spring and early summer. Herbicides are increasingly used as preemergence weed treatment for row crops.

TABLE III-14

AGRICULTURAL HERBICIDES: TYPES, TRANSPORT MODES, TOXICITIES, AND PERSISTENCE IN SOIL (58)

Common Names of Herbicides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]		Approximate Persistence in Soil, days
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter	
Alachlor *	AM	SW	1200	2.3	40-70
Ametryne[5] *	TZ	SW	1110	Low toxicity	30-90
Amitrole	TZ	W	2500	>50	15-30
Asulam	CB	W	>8000	[6] 5000	25-40
Atrazine *	TZ	SW	3080	12.6	300-500
Barban	CB	S	1350	[7] 1.3	20
Benefin	NA	S	800	[6] 0.03	120-150
Bensulide	AM	S	770	0.72	500-700
Bentazon	DZ	W	1100	190	
Bifenox	AR	S	4600	1.8	40-60
Bromacil	DZ	W	5200	70	700
Bromoxynil	NT	SW	250	0.05	
Butylate *	CB	S	4500	4.2	40-80
Cacodylic Acid	AS	S		[8] >40	
CDAA	AM	W	700	2.0	20-40
CDEC	CB	SW	850	4.9	20-40
Chloramben *	AR	W	3500	[6] 7.0	40-60
Chlorbromuron	UR	SW	2150	0.56	
Chloroxuron *	UR	S	3700	[8] >15	300-400
Chlorpropham	CB	SW	1500	[6] 10	120-260
Cyanazine *	TZ	SW	334	4.9	
Cycloate[5]	CB	SW	2000	4.5	120-220
2,4-D Acid	PO	W	370	[9] >50	10-30
2,4-D Amine *	PO	W	370	[8] >15	10-30
2,4-D Ester *	PO	S	500-875	[8] 4.5	10-30
Dalapon *	AL	W	6590	>100	15-30
2,4-DB *	PO	S	300	4.0	
DCPA *	AR	S	3000	>500	400
Diallate *	CB	S	395	5.9	120
Dicamba *	AR	W	1028	35	
Dichlobenil	NT	S	3160	10-20	60-180
Dinitramine*	NA	S	3000	6.7	90-120
Dinoseb *	PH	SW	5	[7, 10] 0.4	15-30
Diphenamid	AM	W	970	25.0	90-180
Diquat	CT	S	400	12.3	>500
Diuron*	UR	S	3400	>60	200-500
DSMA	AS	S	600	>15	
Endothall	PH	W	38	1.15	
EPTC*	CB	SW	1360	19.0	30
Fenac[5]	AR	SW	1780	7.5	350-700
Fenuron	UR	W	6400	53	30-270
Fluometuron *	UR	SW	7900	[10] >60	
Fluorodifen	AR	S	15000	0.18	
Glyphosate	AL	S	4320	Low toxicity	150
Isopropalin	NA	S	5000	Toxic	150
Linuron *	UR	S	1500	16.0	120
MBR 8251	AM	SW	633	312	
MCPA *	PO	SW	650	10.0	30-180
Metribuzin*	TZ	W	1930	>100	150-200
Molinate*	CB	W	501	0.29	80
Monuron	UR	SW	3500	1.8	150-350
MSMA *	AS	S	700	>15	
Naptalam*	AR	W	1770	>180	20-60

TABLE III-14

AGRICULTURAL HERBICIDES: TYPES, TRANSPORT MODES, TOXICITIES, AND PERSISTENCE IN SOIL (58)
(Continued)

Common Names of Herbicides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]		Approximate Persistence in Soil, days
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter	
Nitralin *	NA	S	2000	Low toxicity	
Nitrofen	PO	S	2630	Toxic	
Oryzalin	AM	S	>10000	Low toxicity	
Paraquat	CT	S	150	[6] 400	>500
Pebulate[5]	CB	S	921	[11] 6.3	50-60
Phenmedipham	CB	S	2000	[10] 20	100
Picloram *	AR	W	8200	2.5	550
Profluralin	NA	S	2200	Toxic	320-640
Prometone[5]	TZ	S	1750	[9] >1.0	>400
Prometryne[5] *	TZ	S	3750	[9] >1.0	30-90
Pronamide[5]	AM	S	5620		60-270
Propachlor[5] *	AM	W	710	1.3	30-50
Propanil[5] *	AM	S	1384	> 10.0	1-3
Propazine[5]	TZ	S	5000	>100	200-400
Propham	CB	W	5000	[6] 32	20-60
Pyrazon	DZ	W	2500	[12] 40	30-60
Silvex*	PO	SW	375	[9] 0.36	
Simazine *	TZ	S	5000	5.0	200-400
2,4,5-T *	PO	W	300	0.5-16.7	
TCA*	AL	W	3370	[13] >2000	20-70
Terbacil	DZ	W	5000	[14] 86	700
Terbutryne[5]	TZ	SW	2400	Low toxicity	20-70
Triallate[5]	CB	S	1675	4.9	30-40
Trifluralin *	NA	S	3700	[6] 0.1	120-180
Vernolate[5]	CB	SW	1625	9.6	50

[1] Chemical type designations: AL, aliphatic acids; AM, amides and anilides; AR, aromatic acids and esters; AS, arsenicals; CB, carbamates and thiocarbamates; CT, cationics; DZ, diazines; NA, nitroanilines; NT, nitriles; PH, phenols and dicarboxylic acids; PO, phenoxy compounds; TZ, triazines and triazoles; UR, ureas.

[2] Where movement of herbicides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, and SW denotes those that will most likely move in appreciable proportion with both sediment and water.

[3] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[4] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[5] Trade name; no corresponding common name exists.

[6] 24-hour LC_{50}.

[7] For goldfish.

[8] For killifish.

[9] For spot.

[10] LC_{100}.

[11] For mullet.

[12] For harlequin fish.

[13] For catfish.

[14] For sunfish.

*** Denotes pesticides that are recommended by Texas Agricultural Experiment Station for crops grown in the greater 208 planning region.**

TABLE III-15

AGRICULTURAL INSECTICIDES AND MITICIDES: TYPES, TRANSPORT MODES, AND TOXICITIES (58)

Common Names of Insecticides-Miticides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]	
			Rat, Acute Oral LD_{50}, mg/kg	Fish[4] LC_{50}, mg/liter
Aldicarb[5]	CB	W	0.93	
Aldrin	OCL	S	35	0.003
Allethrin	PY	S	680	0.019
Azinphos ethyl[6]*	OP	S	7	0.019
Azinphos methyl *	OP	S	11	0.010
Benzene hexachloride	OCL	S	1000	0.79
Binapacryl	N	U	120	0.04
Bux[6]	CB	S	87	0.29
Carbaryl*	CB	SW	500	1.0
Carbofuran[5] *	CB	W	8	0.21
Carbophenothion *	OP	S	10	0.23
Chlorbenside	S	S	3000	
Chlordane	OCL	S	335	0.010
Chlordimeform *	N	W	162	1.0
Chlorobenzilate[6]	OCL	S	700	0.71
Chlorpyrifos	OP	U	97	0.020
DDT	OCL	S	113	0.002
Demeton[5] *	OP	W	2	0.081
Diazinon[5,6] *	OP	SW	76	0.030
Dicofol[6]*	OCL	S	684	0.10
Dicrotophos *	OP	W	22	8.0
Dieldrin	OCL	S	46	0.003
Dimethoate *	OP	W	185	9.6
Dioxathion	OP	S	23	0.014
Disulfoton *	OP	S	2	0.040
Endosulfan*	OCL	S	18	0.001
Endrin	OCL	S	7.3	0.0002
EPN	OP	S	8	0.10
Ethion	OP	S	27	0.23
Ethoprop	OP	U	61.5	1.0
Fensulfothion[5]	OP	SW	2	[7] 0.15
Fonofos[6] *	OP	S	8	0.03
Heptachlor	OCL	S	90	0.009
Landrin[6]	CB	SW	178	0.95
Lindane	OCL	S	88	0.018
Malathion*	OP	W	480	0.019
Metaldehyde	O	W	1000	>100.0
Methidathion	OP	U	25	
Methomyl*	CB	U	17	~0.9
Methoxychlor	OCL	S	5000	0.007
Methyl demeton[6]	OP	W	65	4.0
Methyl parathion[6]*	OP	SW	9	1.9
Mevinphos *	OP	W	4	0.017
Mexacarbate	CB	SW	22.5	1.73
Monocrotophos *	OP	W	21	7.0
Naled *	OP	S	250	0.078
Ovex	S	S	2000	0.70
Oxythioquinox	S	S	1100	0.096
Parathion *	OP	S	6	0.047
Perthane[6]	OCL	S	>4000	0.007
Phorate[5] *	OP	SW	1	0.0055
Phosalone	OP	S	96	3.4
Phosmet[6]	OP	S	147	[8] 0.03

TABLE III-15

AGRICULTURAL INSECTICIDES AND MITICIDES: TYPES, TRANSPORT MODES, AND TOXICITIES (58)

(Continued)

Common Names of Insecticides-Miticides	Chemical Class[1]	Predominant Transport Mode[2]	Toxicity[3]	
			Rat, Acute Oral LD$_{50}$, mg/kg	Fish[4] LC$_{50}$, mg/liter
Phosphamidon *	OP	W	11	8.0
Propargite[6]	S	U	2200	0.03
Propoxur	CB	W	95	[9] 0.025
TDE	OCL	S	3360	0.009
TEPP	OP	W	1	[9] 0.39
Tetrachlorvinphos	OP	S	4000	0.53
Tetradifon*	OCL	SW	14000-	1.10
Thionazin	OP	W	12	[7] 0.10
Toxaphene *	OCL	S	69	0.003
Trichlorfon *	OP	W	275	0.16

[1] Chemical type designations. CB, carbamates; N, miscellaneous nitrogenous compounds; O, cyclic oxygen compounds; OCL, organochlorines; OP, organophosphorus compounds; PY, synthetic pyrethrin; S, aromatic and cyclic sulfur compounds.

[2] Where movement of insecticides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, SW denotes those that will most likely move in appreciable proportion with both sediment and water, and U denotes those whose predominant mode of transport cannot be predicted because properties are unknown.

[3] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD$_{50}$ or LC$_{50}$, respectively).

[4] 48- or 96-hour LC$_{50}$ for bluegills or rainbow trout, unless otherwise specified.

[5] Registered as both insecticide and nematicide. Nematodes are controlled only on limited acreage and predominantly in the Southern states, but application rates when used as nematicides are 2- or 3-fold higher than when used as insecticides.

[6] Trade name; no corresponding common name exists.

[7] 24-hour LC$_{50}$

[8] For killifish

[9] For minnows

* Denotes pesticides that are reco-mended by Texas Agricultural Experiment Station for crops grown in the greater 208 planning region.

TABLE III-16

AGRICULTURAL FUNGICIDES: TRANSPORT MODES AND TOXICITIES (58)

Common Names of Fungicides	Predominant Transport Mode[1]	Toxicity[2]	
		Rat, Acute Oral LD_{50}, mg/kg	Fish[3] LC_{50}, mg/liter
Anilazine	S	2710	0.015
Benomyl	S	>9590	0.5
Captafol	S	5000	[4] 0.031
Captan	S	9000	0.13
Carboxin	SW	3200	2.2
Chloranil	W	4000	5.0
Chloroneb	U	11000	>4200.0
Cycloheximide	W	2.5	1.3
DCNA	S	4040	
Dichlone	S	1300	0.047
Dichlozoline	U	3000	
Dinocap	S	980	[5] 0.14
Dodine	W	1000	0.9
ETMT	U	2000	
Fenaminosulf	W	60	23.0
Ferbam	SW	>17000	[4] 12.6
Folpet	S	>10000	[6] 1.56
Maneb	S	6750	[7] 1.0
Metiram	U	6400	>4.2
Nabam	W	395	[4] 21.1
Ocycarboxin	W	2000	
Parinol	U	>5000	[8] ~5.0
PCNB	S	1650	0.7
SMDC	W	820	[7] 1.0
Thiram	S	375	[4] 0.79
TPTH	U	108	
Zineb	S	>5200	0.5
Ziram	W	1400	[4] 1.0

[1] Where movement of fungicides in runoff from treated fields occurs, S denotes those chemicals that will most likely move primarily with the sediment, W denotes those that will most likely move primarily with the water, SW denotes those that will most likely move in appreciable proportion with both sediment and water, and U denotes those whose predominant mode of transport cannot be predicted because properties are unknown.

[2] Expressed as the lethal dose, or lethal concentration, to 50% of the test animals (LD_{50} or LC_{50}, respectively).

[3] 48- or 96-hour LC_{50} for bluegills or rainbow trout, unless otherwise specified.

[4] For catfish

[5] For harlequin fish

[6] For mullet

[7] LC_{100}

[8] For fathead minnow

Pesticides applied to land surfaces advance to receiving streams by adsorption onto soil particles or dissolving in water. If chemicals are loosely held by the soil, they could be leached into the groundwater or dissolved into surface runoff. If they are tightly held by the soil particles, soil losses become doubly important.(32) Some insecticides such as aldrin and parathion are tightly attached to soil particles and only small amounts may be removed by water. Therefore surface waters can become contaminated from some insecticides being adsorbed by the soil and then being washed from the field by runoff water.(60) A study by McCarty and King found the rate of movement of a pesticide in the soil was inversely related to the amount of adsorption.(61) Another study showed that the concentration of herbicides diminished as a function of distance below the treated area and time after application.(62)

Impact. Possible problems of pesticide application relate to three aspects of water quality. The first problem stems from very high pesticide concentrations which result in fish kills or aquatic damage, which is rarely the case and occurs only from the misuse of chemicals. The second problem is the outcome of exposing aquatic life to low-level, long-term dosages of pesticides. The third problem results when pesticides are processed through municipal water treatment facilities.(63) However, effects on water quality as determined from pesticide research in various parts of the nation indicate stream quality is not adversely affected by its use. Most studies conclude that except when a heavy rainfall occurs after immediate application, concentrations are very low, often much less than five percent of the application. Many agricultural chemicals are neither acutely toxic or persistant and under normal application can be used without causing environmental damage.(58) Many do not accumulate in food chain organisms, and therefore can be used at normal application rates without fear of causing unacceptable environmental damage.(58)

The wide acceptance and usage of some insecticides and herbicides has resulted in their becoming virtually ubiquitous. Determinations for these pesticides are often positive even when there has been no known usage of the chemicals in the area. Some investigations report the travel of pesticides in the atmosphere and also finding of these compounds in rainfall.(33) The United States Public Health Service conducted a study to determine the distribution of chlorinated hydrocarbon insecticides in the major drainage basins of the United States and collected water samples for analysis from 41 states. They found widespread distribution of dieldrin, endrin, DDT, and DDE.(64)

A study to quantify the pollutants in agricultural runoff was performed in South Dakota using various drainage basins. The sites had sandy, clay, loam soil and various crops including oats, corn, brome grass, alfalfa, and pasture. The results showed that pesticide concentrations in runoff waters from rainfall and snowmelt were very low with most samples having concentrations below the analytical test limits of 0.05 ppb for aldrin, DDE, dieldrin, lindane, heptachlor, heptachlor epoxide, and endrin and 0.10 ppb for DDT, DDD, atrazine and methoxychlor. Most sediment samples also had pesticide concentrations below the analytical test limits.(32)

No research has been found that gives estimated or measured loadings of pesticides into receiving streams in the Planning Area except those U. S. Geological Survey monitoring stations previously mentioned. The total amount of pesticides used on agricultural lands in the Planning Area are not known. One problem in estimating the amount used on agricultural lands is that much of the pesticides bought are applied in urban areas, with estimates for urban use ranging up to fifty percent.

Table III-17 gives the characteristics of some of the major pesticides used in the United States. Those marked with an asterisk are some of the pesticides recommended by the Texas Agricultural Extension Service for use on crops grown in the Greater Houston 208 Planning Area. Out of the fourteen suggested chemicals, twelve of those have moderate to high rates of degradation, constituting little or no health hazard or detriment to water quality. Almost all pesticides used in rice and soybean production, the two dominant crops of the Planning Area, use the high rate degradation chemicals. The use of pesticides in the forest and timber sections of the area is extremely limited. Recommended control of insect pests by removing infested trees are the dominant program in both private and federal lands. Some use of the chlorinated hydrocarbon insecticides have been employed on small acreages. It can be concluded that there is no significant contamination of pesticides in surface waters from forest areas. Any detectable amounts from these areas are almost certain to come from either urban development or other agricultural land use.

The concentration of various pesticides in surface runoff in the agricultural areas can be somewhat shown by the use of the data collected from monitoring stations operated by the United States Geological Survey and published in the Annual Texas Water Resource Data Publication. They show that the measured concentrations of various pesticides that were sampled throughout the year on streams draining predominantly agricultural areas have minute and relatively insignificant concentrations of pesticides with dieldrin, diazone, and 2-4-D having positive readings. The stations located downstream in urban areas record higher concentra-

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TABLE III-17

PESTICIDES PROPERTIES (55)

Pesticide	Solubility (ppm)	at (°C)	Volatilization Index	Leaching Index	Surface runoff Water	Surface runoff Sed.	Degradation	Persistence	Carry-over
Alachlor *	210	30	3	1.5	minor	minor	rapid	little	none
Propanil *	140	30	2	1.5	neg	neg	1-2 days	little	none
Trifluralin *	< 1		2	1.5	no	low	80%/yr	moderate	possible
Dalapon - Na*	500,000		1	4	yes	yes	60 days	little	no
MCPA	825	30	1	2	yes	yes	rapid	4-6 weeks	0
2,4-D *	620	30	1	2	yes	yes	rapid	4 weeks	0
2,4,5-T*	278	30	1	2	yes	yes	f. rapid	5 months	0
Carbaryl *	NA	30	2.5	2	low	low	mod.-rapid	λ = 7-10 days	0
Malathion *	120	30	2	2.5	low	poss	rapid	< 2 weeks	0
Naled	2,000		4	3	poss.	low	v. rapid	λ = 4 hr	0
Dimethoate*	30,000	30	2	2.3	high	poss.	low in water	3-4 days	0
Fenthion	55	25	2	2	low	poss.	moderate	low, 6 months	0
Diazinon *	40	20	3	2	poss.	poss.	mod. rapid	4-6 weeks	0
Ethion	2	25	1.5	1.3	low	poss.	rapid	90% in 30 days	0
Azinphos-methyl*	25	30	NA	1.5	nil.	low	rapid	low	< 10%/yr
Phosphamidon	mis.	30	2.5	3.5	high	poss.	NA	NA	0
Mevinphos	mis.	30	3.5	3.5	high	nil.	rapid	3-12 hr	0
Methyl Parathion*	55	20	3	2	low	low	v. rapid	not persist.	0
Parathion*	9	20	2	2	low	poss.	moderate	not persist.	0
DDT	insol.		1	1	low	high	v. slow	v. persist.	v. high
BHC	10	20	3	1	nil.	minor	v. slow	v. persist.	yes
Chlordane	insol.		2	1	nil.	NA	slow	λ = 1 yr	yes
Heptachlor	0.01	20	3	1	nil.	NA	slow	λ = 1 yr	yes
Toxaphene*	0.0.4	25	4	1	nil.	poss.	slow	v. persist.	poss.
Aldrin	0.011	20	1	1	no	high	slow	v. persist.	v. high
Dieldrin	0.11	20	1	1	no	high	slow	v. persist.	v. high
Endrin	0.16	20	1	1	no	low	slow	persist.	high
Captan	3.3	25	2	1	low	NA	rapid	λ = 2 weeks	0
Benomyl	0	20	3	3.5	no	no	NA	NA	NA
Zineb	v. slight		1	2	low	low	rapid	not	0
Maneb	v. slight		1	2	low	slight	NA	1-2 weeks	0
Mancozeb	v. slight		1	2	no	poss.	rapid	not	0
Methyl Bromide	slight		NA	all	no	no	rapid	λ = 55 days	0

Source: Pesticide Manual, R. von Rümker and F. Horay, USAID, August 1972.

Volatilization Index
1 = volat. loss < 0.1 kg/ha/yr
2 = volat. loss 1
3 = volat. loss 5
4 = volat. loss > 10

Leaching Index
Distance of travel through loam soil profile under 150 cm/yr rainfall
1 = movement of < 10 cm
2 = movement of 10-20 cm
3 = movement of 20-30 cm
4 = movement of < 30 cm

* Denotes pesticides that are recommended by Texas Agricultural Experiment Station for crops grown in the greater 208 planning region.

tions of these same chemicals and list several more not found in the agricultural watershed. It should be noted that the station on Buffalo Bayou draining the most urban area shows the highest concentrations of pesticides of any of the three stations on the stream. (See Table III-11) This indicates that the major contribution of residual pesticides found in streams in the Greater Houston 208 Planning Area comes not from the agricultural sector but from urban lands.

Impact of Animal Waste on Stream Quality

Runoff from confined animal production has the following effects on stream quality:

1) Increases concentration of nutrients in the water;

2) Raises the level of bacteriological organisms in streams;

3) Depletes the dissolved oxygen in streams as the wastes undergo decomposition.

In order to evaluate the amount of impact from animal wastes, a summary of a study performed in North Carolina (52) concerning the role of animal waste is presented. The report includes a study on swine, dairy, beef, and poultry production and the conclusions are as follows:

> "Except for nitrate penetration into the groundwater at one site, pollution indices for land drainage from waste spreading and control watersheds paralleled stream hydrographs with extended dragout on cessation of surface runoff. The rise in indices with runoff was roughly proportional to increase in flow of stream over base flow. Where nitrate had entered the groundwater, concentrations in stream were inversely proportional to flow, peaking under dry-weather conditions.
>
> The extent of water pollution caused by farm animal production units is more dependent on production and waste management practices than on the volume of wastes involved.
>
> The land provides a natural treatment system for animal wastes and land spreading is a very effective means to prevent water pollution. Even in cases where the disposal sites are poorly located or managed or where pastured animals have access to streams, the amount of pollutants (natural plus animal wastes) which reach streams is a very small proportion (less than 10 percent) of the potential from the animal wastes deposited in the watersheds. Proper land

> spreading can reduce pollutants entering streams by more than 99 percent. Criteria for this purpose are provided.
>
> Differences in watershed characteristics such as slope, soil permeability, surface culture, drainage pattern, degree of erosion, and other factors are of great significance in determining the quality of streams draining agricultural basins. This emphasizes the importance of good soil and water conservation practices to minimize the movement of wastes into streams.
>
> Although estimating equations developed from this study with temperature, number of animals and rate of land runoff as independent variables and pollution parameters as dependent variables do not have general applicability, predictive relationships held quite well for many sets of data collected over short periods of time showing promise that estimating equations to serve the needs of water quality management can be developed with a more detailed and longer term study, particularly if the equations include effects of more hydrological variables.
>
> The large pollution load imposed on a stream by a direct discharge operation overshadows the load from surrounding pastures or other land disposal operations. The streams are generally more polluted in the summer and pollution increases with surface runoff."

The average amounts of wastes in land runoff from representative animal-growing operation are shown in Table III-18.

Impact of Animal Wastes. The Greater Houston 208 Planning Area has relatively little confined animal production in its boundaries. There are no beef feedlot operations and the only type of confined animal production that was found were two small poultry operations located near the town of Katy. There are approximately forty dairies within the entire area, located mostly in the northwest portion of the Planning Area. These dairy operations cannot be considered confined animal production, as in case of feedlots, because the cattle are kept in pasture and range lands except during milking and feeding periods. The remaining cattle are raised in predominantly pasture and range lands and are not produced in small pens operations. The small amounts of swine production [only 4,000 hogs were solid in Harris County in 1975 (65)] are located throughout the entire area and constitutes negligible impact on stream pollution.

Because the cattle and horses are spread over large acreages in the Greater Houston 208 Planning Area, it can be concluded

TABLE III-18

ANIMAL-GROWING WASTES IN LAND RUNOFF OF REPRESENTATIVE OPERATION (52)

	Fecal Coliform	BOD_5	TOC	N	PO_4
	10^6 coliform /day/animal		lb/day/animal		
Swine					
Direct discharge[1/]	30,000	0.176	0.128	0.032	0.017
Anaerobic lagoons[2/]	910	0.154	0.156	0.009	0.005
Land spreading[3/]	630	0.003	0.007	0.002	0.001
Dairy[1/]	60,000	0.190	0.023	0.034	0.027
Beef[2/]	430	0.030	0.100	0.008	0.003
Poultry[3/]	0.6	0.0005	0.0007	0.0002	0.00003

[1/] Sampling station downstream from point of discharge with intervening section of stream providing some stabilization and settling.

[2/] Lagoon effluent.

[3/] Sampling station at base of watershed immediately below site.

that the runoff from these acreages does not produce any significant degradation to stream quality. Research shows that manure distributed over land increases the organic matter content of the soils, which increases infiltration capacity, thus reducing runoff and erosion. The poultry operations in the Planning Area have negligible effects on water quality due to the spreading of the manure on farmland. As shown of Table III-18, the total BOD_5 loading for 10,000 birds (the approximate number in each operation) is only five pounds per day, which is the equivalent BOD_5 loading of only thirty urban dwellers.

Impact of Irrigation Return Flows on Water Quality

The dominant crop that is irrigated in the Planning Area is rice. In 1974, Harris County recorded 31,932 acres of irrigated rice fields with no other cash crop being irrigated.(65) In 1975, 31,560 acres were irrigated for rice production.(65) Almost all of the rice fields are in the western portions of Harris County and are located in the Spring Creek, Cypress Creek, and Buffalo Bayou watersheds. The parts of Waller, Galveston and Fort Bend Counties included in the Planning Area would also be included in these watersheds and do contain some irrigated rice fields. Exhibit III-3 shows the location of the rice fields in Harris County.

Rice Farming. Most rice is grown between the months of April and August with harvest usually around late August. Germination of seeds can be either by drilling seeds into the soil, or by the water plant method, the flooding of the land until the rice plants are several millimeters high and then releasing the water. After plants are 20 to 25 days old, there will be a permanent flooding of the rice fields. This flooding will be released shortly before the rice is ready to harvest to allow partial drying of the ground. On the average, which varies considerably with the weather, rice requires three acre-feet of water/acre for crop production.

Impact of Nutrients. The application of fertilizer will contribute to concentrations of phosphorus and nitrogen in the flood waters of rice basins. However, the high concentration of nutrients after application of fertilizer readily disappears and is either filtered through the soil or taken in by the plants. It has been found that if the flood waters are not released until at least seven to ten days after application of fertilizer, there is very little nutrient gain from the flood waters into the receiving stream.(16) Preliminary findings show that concentrations of phosphorus and nitrogen in rice flood waters are below the contaminant level for primary drinking water standards proposed by the Environmental Protection Agency.(16) If released before seven days, highest concentration that was found was 18 mg/1 of ammonia nitrogen and the normal concentration was in the range of 10 to 12 mg/1 ammonia nitrogen. Depending on the depth of water, but in an average situation, this can be converted to an approximate 10 to 12 pounds per acre of rice acreage.

Impact of Pesticides and Herbicides. Two of the more common herbicides used by rice farmers are propanil and ordran. Two insecticides under study are sevin (carybaryl) and furadan.

The herbicides are used for the control of weeds and are applied at the beginning of the season. Pesticides are applied during the growing season for control of insects; and, at times, close to harvest, for the control of stink bugs. These chemicals degrade at a high rate in the water and are adsorbed by the plants. It has also been shown that with the heavier textured soils, common in rice farming, there is a decrease in movement of pesticides. After two weeks from the time of application of the pesticides, it becomes difficult to find traces in the flood waters.(66) As in the case of fertilizer, given sufficient time after application before release of the flood waters, no significant damage to the water quality of the receiving streams should be expected from pesticides.

Impact of Sediment. The irrigation water for rice farming comes either from surface water supplies through canal systems or from groundwater sources directly by pumping from the underground aquifers. There is a difference of water quality between the two sources and the surface supplies have much larger amounts of sediment being carried by the water, especially in those canals that have been reworked recently. These waters are found to be significantly muddy when released to the receiving streams.(66) The settling of the larger sediment through the filtering of the rice plants will significantly reduce the total sediment loading. No data was found to indicate if a decrease or increase of sediment concentration to surface water occurs when groundwater supplies are used. Irrigation water from wells has turbidity that is less than the receiving streams themselves.

Unforseen Events Leading to Significant Pollution. Good management in rice farming may have a positive impact to the stream quality in the area due to the reduction of nutrients and chemicals coming from flood water. Deterioration of stream quality can be caused by a levee breaking during a storm whereby the release of all the water is unavoidable. An occurrence of this nature would probably have a strong possibility of increasing sediment and nutrient loading in the stream. Also the release of some water during a storm because of heavy rains after application of a pesticide or herbicides may increase loadings in streams and therefore have impact on stream quality. However, good management in application of chemicals when the levee does not have a maximum amount of water can prevent these occurrences.

Summary. The following is an excerpt from the preliminary results published by the Rice Center:

1) "Nutrient (fertilizer) concentration in floodwater.

Nitrate and phosphate concentrations were below 0.1 ppm.
Ammonium concentration was as high as 20 ppm immediately after fertilizer application but dropped to insignificant levels within seven days.

2) Herbicide concentrations in floodwater.

Propanil applied to non-flooded field dissipated within 24 hours after flooding.
Ordram persisted up to 16 days but was below 1 ppb six days after applied to floodwater.

3) Insecticides concentrations in floodwater.

Sevin was no longer detectable four days after application.
Furadan concentration fell below 0.1 ppb within four days but persisted at low concentration for 16 days.

4) These preliminary findings indicate that the rice fertilizers, herbicides and pesticides tested contribute insignificantly to water pollution provided proper water management techniques are adhered to."(66)

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PRELIMINARY ASSESSMENT OF CONSTRUCTION AND DREDGING ACTIVITIES

Construction Activities

The major water pollutant generated by construction sites is considered to be suspended sediment (both mineral and organic solids), most commonly dispersed and transported from its site of origin by the action of water and wind. (1) Sources of pollutants other than sediment associated with construction activity include pesticides, nutrients, solid wastes, construction chemicals, petroleum products and sanitary wastes.

An alleviating factor in construction work, as contrasted with other nonpoint source activities which generate water pollution, is that construction is relatively short-term activity--disturbances or displacements of soil and vegetal cover generally cause only temporary and localized increases in the potential for erosion or production of other pollutants. During the interval that the land is disturbed, the soil loss or the runoff of chemicals will hinge on probabilistic intensities, durations, and runoffs of precipitation. Mining and agricultural pursuits, by comparison, might be expected to last for decades or even idefinitely. A possible exception to short-term nature of construction activities is maintenance dredging, that is, redredging to preserve navigation channels at specified depths and widths. This activity may be repeated intermittently over the useful life of a channel.

The nature of the water quality impact of construction activities is shown by two exhibits. (2) Table IV-1 shows the relative amounts of various types of pollutants released by each type of activity, and indicates the beneficial and adverse effects on the receptor water body. The relative quantity (or release rate) of each pollutant type is shown as three levels: high (H), moderate (M), and low (L). For sediment, the release rate was estimated relative to the release rate from a predisturbed land surface (which may have been forested, grass covered or poorly vegetated) or a predisturbed benthic area. For other types of pollutants, the quantities released were estimated relative to the concentrations of the same type of pollutant in urban surface runoff. These estimates of pollutant quantity or release rate were made by the EPA and are not based on field measurements or data reported in the literature.

Table IV-2 identifies in greater detail the use of specific pollutants introduced by various types of construciton activities, and indicates the nature of the effects from each class of pollutant.

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TABLE IV-1

EFFECTS OF CONSTRUCTION PROJECTS ON WATER QUALITY

CONSTRUCTION ACTIVITY	RELATIVE QUANTITY RELEASED BY CONSTRUCTION[a]							EFFECTS OF POLLUTANTS	
	SEDIMENT	NUTRIENTS	DISSOLVED SOLIDS HEAVY METALS	SALINITY	BIODEGRADABLE ORGANICS	REFR. ORGANICS PESTICIDES	OILS AND SYNTHETIC CHEMS.	BENEFICIAL	ADVERSE
OUT-OF-STREAM ACTIVITIES (EARTH MOVING)									
• AREAL (Suburban Devm't -- residences, streets, shopping centers, parking lots, public buildings; Business/Commercial Devm't; Reclamation Landfills -- tunneling spoil disposal[b], dredging spoil on-land, earth dams. Construction -- dams, reservoir areas, bridges.)	H	M	L	L	L	L	L	Sediment produced which may sustain a receptor stream at equilibrium suspended sediment load; can help remove ions in receptor water body by adsorption.	May alter the physical and and biological character of the receptor water body, if subjected to excessive sediment. Results in costly loss of flora and fauna, stream cross-sectional changes, altered flow regimes, and added water treatment requirements. Biostimulation of water bodies from nutrient runoff. May cause siltation of downstream reservoirs.
• LINEAR (Highways; Railroads; Pipelines; Power Lines; Channels/Canals/Flumes/Floodways/Drainage Ditches; Levees)									
IN-STREAM									
• Dredging Operation/In-Water Channel Excavation, Stream Realignment	H	M	M	L	L	L	L	Suction dredging of benthal deposits may remove undesirable heavy metals and other chemical pollutants to accelerate recovery of polluted	Local temporary increase in suspended sediment and turbidity with potentially damaging effects on marine life and degraded water quality for consumptive uses. Can physically remove shellfish from their habitat. Can change channel shape, with ensuing scour or aggradation imposes requirements for grade control structures, concrete linings, or rip rap to stabilize the channel.

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[a] H(high), M (moderate) or L (low) release rates are estimated relative to expected yield from predisturbed surface on benthetic areas for sediment, and relative to urban runoff for chemical pollutants.

[b] Outflow from exit considered to be a point source.

TABLE IV-1
(contd.)
EFFECTS OF CONSTRUCTION PROJECTS ON WATER QUALITY

CONSTRUCTION ACTIVITY	RELATIVE QUANTITY RELEASED BY CONSTRUCTION							EFFECT OF POLLUTANTS	
	SEDIMENT	NUTRIENTS	DISSOLVED SOLIDS HEAVY METALS	SALINITY	BIODEGRADABLE ORGANICS	REFR. ORGANICS PESTICIDES	OILS AND SYNTHETIC CHEMS.	BENEFICIAL	ADVERSE
IN-STREAM (Cont'd)									
• Dredge Spoil Dumping in Water, In-Water Fills, Causeways, Retarding Basins, Levees, Floodwalls	H	H	M	L	L	L	L	May create new land for waterfowl habitats and decrease levels of insect breeding in filled-in marshes. Stream blockages provide storm water storage and trap silt, provide fish and wildlife habitat, aesthetic improvement.	Constructed channels scour heavily during flooding. Can smother marine life on bottom, destroy fin fishes, lower dissolved oxygen levels, increase turbidity thereby reducing light transmission. Change original fish and wildlife habitat. Aquatic life stressed by temperature, chemical and biochemical equilibria changes.
• Installation of Piles, Bulkheads, Dikes Marinas	H	L	L	L	L	L	L		Benthic penetration and some disturbance of bottom material ensues, causing local resuspension of sediments.
• Channelization (Stream Realignment, Clearing and Snagging)	H	L	L	L	L	L	L	Improves flow efficiency and navigation. BOD lower with lower detritus.	Temporarily increases suspended sediment and turbidity. May decrease concentration time of peak runoff and increase flooding downstream. Removes obstructions used by fish for protection, food support, and breeding areas.

TABLE IV-2

WATER POLLUTION FROM CONSTRUCTION ACTIVITIES
CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY[a]	EFFECTS	
CLASS	MATERIALS			BENEFICIAL	ADVERSE
Physical					
• SEDIMENT	Inert and organic particles; colloids; microorganisms (Note: during transport, the sediment load comprises the suspended load plus the bed load.)	Land-Disturbing Operations: Surface-clearing, grading, excavating, trenching, stockpiling; (Note: Subsoils often have different erodibility characteristics than surface soils)	H	May provide material to maintain a receptor stream channel in equilibrium, i.e., provide adequate suspended sediment to prohibit erosive degradation of a fluvial channel. In-stream sediment required in formation of silt-laden farmlands along flood plains and near river mouths. Fine-grain sediment helps in the removal of ions which adhere to and are transported by particulates, which settle to the bottom. Dredge spoil disposal may also create new land areas (for building sites, beach restoration, waterfowl habitats) and decrease vectors in marsh-filling.	May exceed equilibrium suspended load of receptor stream altering many phy .cal and biological characteristics of the channel; these include channel aggredation, silting of reservoirs, undesirable effects on marine life such as blanketing and smothering of benthic flora and fauna; altering the flora and fauna as a result of changes in light transmission and abrasion, destroying or altering the species of fish due to changes in the flora and fauna upon which the fish depend, or obstruction of their gill function. Also a need may arise for excessive treatment (sedimentation, clarification) prior to consumptive use for municipal, industrial, or irrigation purposes. Channel siltation can adversely affect its capacity to carry flood flows or support navigation and recreation. Dredge spoil disposal may destroy land areas (salt marshes, wildlife refuge, vegeted coverage), block flow circulation or increase vectors in the spoil pile.
		Channel Modification: Dredging, waste disposal, excavation, fill, penetration of bed	M		
		Cleaning Operations: Aggregate washing, cleaning of masonry surfaces, forms and containers	L		

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[a] H (high), M (moderate) or L (low) release rates are estimated relative to expected yield from predisturbed surface on benthetic areas for sediment, and relative to urban runoff for chemical pollutants.

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TABLE IV-2
(contd.)
WATER POLLUTION FROM CONSTRUCTION ACTIVITIES CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY	EFFECTS	
CLASS	MATERIALS			BENEFICIAL	ADVERSE
Chemical					
• NUTRIENTS	Ammonia, orthophosphates, polyphosphates, organic N, organic P	Fertilization of reestablished vegetal cover	L	Stimulates growth of plants and grasses on areas denuded by construction (especially on slopes), thereby reducing soil loss in rain storms	Nutrients, especially from excessive application of soluble fertilizers, will be transported from new-growth surfaces at construction sites in the runoff of precipitation; by then stimulating growth of algae and marine plants, nutrients can have adverse effects on chemical exchange processes, leading to eutrophication and lowered oxygen levels. In addition to the biostimulation impacts, large concentration of unoxidized nitrogen (organic nitrogen and ammonia) could represent a significant oxygen demand in the receiving waters.

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TABLE IV-2
(contd.)
WATER POLLUTION FROM CONSTRUCTION ACTIVITIES
CAUSE/EFFECTS MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY	EFFECTS	
CLASS	MATERIALS			BENEFICIAL	ADVERSE
• DISSOLVED SOLIDS/ HEAVY METALS	Ionic Hg, Pb, Zn, Mn, Co, Cr, Ag, Cd, As, Cu, Al, Fe	Derived from construction wastes such as discarded metallic frames, ducts, pipes, wiring, beams, gypsum board; also from fuels, paints, pesticides, and other construction chemicals. Also, concrete operations produce NPS, e.g., spilled cement, washing water, curing compounds.	L	A light, distributed concrete spillage or wash disposal may act as a cementitious stabilizer to reduce soil erosion; also it will add alkalinity which could correct acid soils	When these materials weather, decompose and disintegrate (recognizing that many of the substances such as plasterboard are only slightly soluble in water), the resultant oxides and salts dissolved in water bodies may damage or destroy aquatic organisms; also higher concentrations of certain of the dissolved solids are toxic to humans.
		Dredging activities may reintroduce and disperse within the water column dormant layers (confined by silt deposits) of heavy metals trapped in bottom sludge deposits generally originating over long time periods from point industrial sources and urban runoff.	H Note: may be significant in certain sluggish rivers, lakes, or bays, especially in first-dredging; generally insignificant buildup would occur by the time that maintenance (repeat) dredging is undertaken	Suction dredging and disposal of undesirable chemicals in benthal deposits may accelerate recovery of polluted water bodies, in parallel with introduction of clean inflows.	Dredging may mechanically reintroduce these chemicals into waters, with subsequent diffusion and increase in undesirable impact described above.
• SALINITY	NaCl $CaCl_2$	Produced from saline ice-removal compounds in cold climates (construction roads), dust control on graded areas, and concrete additives (freezing-depressant additives or early strength-enhancing agents, curing compounds). Affected by hydraulic changes resulting from channelization.	L Note: minor level, depending on nature and seasonality of construction activity	Use of salt compounds allows continuation of projects throughout a greater range of climatic conditions, reduces air pollution from dust	Increased salinity of water impacts upon nature of marine-life-plants and animals--indigenous to the region; quality may be degraded for municipal, industrial, or irrigation uses.

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TABLE IV-2
(contd.)

WATER POLLUTION FROM CONSTRUCTION ACTIVITIES CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY	EFFECTS	
CHEMICALS	MATERIALS			BENEFICIAL	ADVERSE
• BIODEGRADABLE ORGANICS	Submerged or floating brush, lumber, tree trunks or limbs, paper, fiberboard	Improper disposal of building products or poor clearing and clean-up practices	L	Larger submerged objects may serve as a temporary habitat of fishes. Permitting growth, wood chips, and similar matter to remain in place in a future inundation area will temporarily reduce out-of-stream erosive losses by serving as a precipitation energy absorber and a sheet runoff retardent.	In degrading of the organics an oxygen demand is exerted on the receiving waters. The dissolved oxygen depression, or large resultant fluctuations in DO, can lead to death of aquatic organisms, severe changes in types and numbers of aquatic organisms, obnoxious odors, and nuisances such as aesthetic impacts, clogging of pumps, screens, etc.
• REFRACTORY ORGANICS/ PESTICIDES	Highly persistent chemicals, heat resistant, or effectively non-degradable, e.g., certain pesticides and other synthetic organics (solid construction materials and tools of polyvinyl chloride, thermoplastic polyesters, rubber, and epoxy fibers and liquid chemicals for treatment of walls, adhesive applications crack-sealing, waterproofing, painting, and curing operations.) Major categories of insecticides include the chlorinated hydrocarbons--complex organic molecules of C,H,Cl--such as chlordane, malathion, DDT, and the phosphorothioates--C,H,P. Herbicides include 2,4,D and 4,5,T.	Improper care in construction applications, overusage, spillage. (Note: some of these types of pollutants, particularly the solids, are expected to remain at the source or point of application, with negligible overland transport). Trend in construction in use of biocides is away from inorganics and toward synthetic organics for use as insecticides, herbicides, fungicides, and fumigants.	L Note: expected level of production is very low because most pesticides are too expensive to be wastefully applied, resulting in efficient or optimal usage.	Underslab and foundation treatment with long-lasting insecticides, especially for termite control, is an important usage; herbicidal treatment of soil areas to remove herbaceous and woody plants that obstruct development and for weed control prior to revegetation is necessary in many construction projects.	Toxic to a wide spectrum of marine biota; can concentrate (by biomagnification) in aquatic organisms, and the effects can be transmitted through higher levels of the biological food chain up to humans. Most biocides show a tendency to accumulate in bottom muds. Earth-moving may reexpose pesticides previously applied to a site, e.g., if used previously for agriculture.

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TABLE IV-2
(contd.)

WATER POLLUTION FROM CONSTRUCTION ACTIVITIES CAUSE/EFFECT MATRIX

POLLUTANT		SOURCE ACTIVITIES/OCCURRENCE	QUANTITY*	EFFECTS	
CHEMICALS	MATERIALS			BENEFICIAL	ADVERSE
• OILS AND SYNTHETIC CHEMICALS	Petroleum products such as oils, grease, tars, asphaltic materials, fuels, solvents; paints, detergents, soaps, sealants, adhesives, chemical soil stabilizers	Introduced into soils through improper construction and maintenance practices, (such as not using adequate caution and methods in disposing of oil wastes, transporting and transferring fuels and lubricants, oil-laden rags, and degreasing compounds), and from spills, for example, from storage tanks. Spillages during routine construction and leaks from trucks and other machinery are also serious considerations. Production of water-bitumen mixtures from road paving, roofing, and waterproofing jobs can also cause NPS concern.	L		Some of these chemicals float over water, some become entrained in water --absorbed on sediment--and some dissolve in water; but all are extremely difficult to control after entering water bodies. These categories of substances impair the use of water for drinking and for contact sports because they impart persistent odors and tastes to water. Some may block the transfer of air through a water-floating substance interface, suffocating aquatic plants, organisms and fish. Some petroleum products contain organo-metallic compounds and other impurities toxic to fish and other organisms.
Biological • COLIFORM	Disease-causing pathogens: soil organisms and those of human and animal origin (bacteria, fungi, viruses).	Improperly planned and managed construction sites where inadequate sanitary conditions prevail.	L M Note: Majority of biological pollutants exist in topsoil layers where they feed on dead organisms; however, construction often disturbs the lower subsoils.	Sludge from wastewater treatment plants may promote and accelerate the restoration of graded areas.	Can cause diseases in humans and animals when released or made available in water bodies.

Pollutant Loads from Construction of Transportation Facilities

The construction of transportation ways, especially highways, is one of the most conspicuous and, in many locally affected areas, the largest sources of water pollution. The pollutant is mainly sediment, but runoff from construction sites may contain fertilizers, pesticides, and other agricultural chemicals used in planting operations to stabilize exposed soil as well as washing from concrete or bituminous mixing and finishing operations.

Present Level of Highway Construction. In 1972 the Federal Highway Administration developed statistics on the land area covered by the Nation's highways and streets. The total system covers some 9.4 million acres (paved surfaces and shoulders) and includes within its rights-of-way a total of 21.7 million acres or about 34,000 square miles. (3)

In an analysis for different types of roadways (4-lane divided or dual highway, and 2-lane highway) in parts of Maryland having markedly different geographic character (coastal plain, rolling Piedmont and mountainous areas), Wolman and Schick (4) found ratios of exposed area per linear mile ranging from 8.8 acres/mile for 2-lane roads in flat country to 25.5 acres/mile for 2-lane roads in flat country to 25.5 acres/mile for four-lane highways in rolling country. These authors estimate that construction of a dual-lane highway (arterials) in the Piedmont area of Maryland would yield an average of 3000 tons of sediment per linear mile, and 1500 tons per mile for two-lane highways (collectors).

Present Rates of Sediment Production from Urban Development. While urban development is not the largest contributor of sediment in our Nation's streams, it does add substantial amounts that often produce a severe impact on water quality in heavily populated watersheds. It is estimated that an average of 40 to 50 tons of sediment can be expected per acre of urban construction. (8) Wolman showed that sediment yields form urbanization ranged from 1,000 to more than 100,000 tons/mi^2/year, which for very small areas may exceed 2,000 to 40,000 times the amount eroded from farms and woodlands in an equivalent period of time. (9) The Soil Conservation Service estimates that sediment from construction in general produces ten times the amount of sediment from cultivated row crops, 200 times more than pasture land, and 2,000 times more than timber land. (10) Taking population into account, Wolman estimates that in Baltimore County, Maryland, construction for one person results in 1.8 tons of sediment and in Prince Georges County, Maryland, this figure is 0.7 tons/person. (12)

Methodology for Projected Sediment Loads from Construction Activities

Quantitative Observations

Several basic quantitative observations relating quantities of pollutant (sediment) produced per unit increase in population from the basis of estimates of projected pollutant loads from construction. These relations are summarized below. (11)

1) The Prince Georges County, Maryland, an estimated 700 tons of sediment were produced for each population increase of 1000. (Of this amount, 62 percent or 430 tons was attributed to highway construction and 38 percent or 270 tons or areal construction).

2) In Baltimore County, Maryland, 1800 tons of sediment were produced per 1000 increase in population (of which 36 percent or 650 tons was attributed to highway construction and 64 percent or 1150 tons to areal construction).

3) Approximately 10,000 tons of sediment are produced per square mile of area urbanized. A typical housing unit, including lot, occupied about 0.00502 square miles (or about 14,000 square feet).

Averaging the sedimentation rates for the two Maryland counties yields a total rate of about 1250 tons per 1000 population increase, or a rate of 480 tons per 1000 population for areal-type construction exclusive of highways. (Local city or subdivision streets are included in the areal development rates discussed below).

If these rates are applied to the projected population increase of about 54.5 million for the Nation over the period 1973-1990 a total sediment production of 682 million tons is obtained from all construction, or about 263 million tons from areal construction alone.

A second approach to estimating sediment yield from areal construction is to utilize the U.S. Department of Agriculture's projections for new housing (12), which total some 48.4 housing units over the 1973-1990 time period. This figure, taken with Wolman's estimate cited above of 0.00502 square miles/housing unit, implies that about 26,000 square miles would be affected. At the above cited yield rate of 10,000 tons sediment per square mile, an estimate of 260 million tons sediment yield for the 1973-90 time period is obtained.

A third approach is to utilize the observation by Guy and Jones (10) that about 1500 square miles of land area are urbanized annually in the U.S.; thus about 27,000 square miles would be disturbed over the 1973-90 interval. At the sediemnt yield rate of 10,000 tons/square miles cited above, a total of 270 million tons of sediment would be produced during the period 1973-90.

Thus three estimates for sediment yield from areal-type construction sources are obtained for the period 1973-1990: 263 million tons, 260 million tons, and 270 million tons. These estimates average to about 264 million tons for the 17 year period, or about 15.4 million tons per year.

Summary of Results for Out-of-Stream Construction: Comparisons, Qualifications, and Caveats

From the two preceding subsections the following totals are obtained:

	Millions of Tons of Sediment Produced	
	1973-1990	Per Year
Areal Construction (Urban)	264	15
Linear Construction (Roadways)	265	15
Total	529	30

The accuracy of these amounts, which have been computed for the entire United States, is dependent on the extent to which Wolman's observed rates for urbanizing areas and highway construction sites in Maryland may be applied to the entire country. Whether or not the Piedmont area is representative of the entire nation is highly debatable. Further, these rates also assume that construction techniques will remain the same through 1990. Regardless of what control measures may be applied, changes in construction technique may have effects on the duration of activities or the amount of area involved and thus could reduce or increase the amount of sediment produced. Further, while the projections used concerning population are widely accepted, these too, must be considered as subject to revision in the light of recent trends in population change and economic growth. These estimates are course and should be treated as such.

Efforts to Apply Soil Loss Equations to Construction Sites

In addition to studies on delivery ratios, other investigations have recently considered the applicability of soil loss equations to construction sites. Wischmeier and Meyer illustrated the use of the soil erodibility factor and the erosion equation to predict sediment yield from construction sites, and interpret other factors in the soil loss equation relative to conditions at construction sites.

Meyer, Wischmeier, and Daniel report a very close comparison between a prediction by the Universal Soil Loss Equation for a given subsoil and the average of observed sediment losses under simulated rainfall losses from experimental plots shaped to simulate conditions in a construction area. (13) Plots were graded to 12-percent slope with surfaces scalped, scarified, or compacted-fill treatments. Close comparisons between observed sediment losses at the experimental plot and predicted losses by the Universal Soil Loss Equation were obtained in this study.

Available Data. There is a serious lack of field-measurement data on sediment loss and related factors for construction sites. In an EPA study, some 500 documents and unpublished studies were examined as potential sources of data for the various parts of the report. Of these case studies, only eight were chosen to supply data for the development of loading functions for construction activities.

It must be recognized that none of the case studies were designed to supply data for developing a loading function. It could not reasonably be expected that the data reported by such a study would be perfectly suited to this purpose. Only the most complete of the available sources were chosen. Even so, many approximations of missing data had to be made.

1) Locations of Missing Data

The study sites are located in several areas of the country, but do not represent a cross-section of all conditions. Four are in the Piedmont of Maryland and Virginia. Two are in the Southern Piedmont: Georgia and North Carolina. One is in the mountains of central Pennsylvania and one is near San Francisco Bay in California.

The most complete studies of full-scale construction site were located near Washington, D.C., and include:

- Yorke and Davis of the U.S. Geologic Survey in the Rock Creek - Anacostia River basins in Montgomery County, Maryland. (14)
- Vice, Guy and Ferguson, U.S.G.S., in the Scott Run Basin in Fairfax County, Virginia. (15)
- Guy and Clayton, U.S.G.S., at Reston, Virginia. (17)

The other studies used were by:

- Reeder, of the U.S.G.S., in the northwestern Wake County, North Carolina. (18)

- Diseker and Richardson, S.C.S., in Cartersville, Georgia, (19)
- Reed, U.S.G.S., Harrisburg, Pennsylvania. (20)
- Knott, U.S.G.S., in Colma Creek, California. (21)

2) Completeness of Data; Parameters Reported (2)

For purposes of loading function development, each case study would ideally include, as a minimum: descriptions of soil type, description of terrain (contours/surface soils), time-correlated measurements of rainfall, snowfall, total water runoff, sediment yield, changes in area exposed by construction activities, changes in slope of exposed areas, changes in type of soil exposed and its compaction, and changes in location of exposed areas with respect to receiving watercourse. None of the available data sources included all of these variables, although it was possible to estimate some of the missing data from maps, site layout sketches, and general engineering knowledge of the type of construction. A primary concern in the selection of case studies was to minimize the number of estimates to be made.

Since the loading functions under development were closely related to the Universal Soil Loss Equation, it was highly desirable that the case studies include data that would permit evaluation of the factors in this equation. Also, since the loading functions would probably involve a "delivery-ratio" factor based on distance between disturbed area and receiving stream or on percent of watershed disturbed, it was desirable to have measurements of these factors also. In summation, the desired variables are:

-sediment yield
-rainfall data
-soil type
-slope steepness of disturbed area
-slope length of disturbed area
-condition of disturbed surface
-type of erosion control measures (if any)
-distance of disturbed area from receiving stream
-percent of watershed disturbed by construction

Figure IV-3 (2) shows which of these variables were measured and reported in the eight case studies used to develop the loading functions, which were obtained from other sources, and which were estimated from site layouts or eningeering judgement.

It can be seen from Table IV-3 that most of the needed data were either provided by the author or obtained from reliable

TABLE IV-3

DATA FROM CASE STUDIES AND OTHER SOURCES

	Yorke & Davis Rock Creek Study									
	Lutes Run (Md)	Bel Pre Creek (Md)	Manor Run (Md)	Vice, Guy, Ferguson Scott Run (Va)	Guy Kensington (Md)	Guy Storm Agnes (Reston, Va)	Reed Harrisburg (Pa)	Diseker & Richardson Cartersville (Ga)	Reeder I-40 (N.C.)	Knott Colma Creek (Ca)
Sediment yield	X	X	X	X	X	X	X	X	X	X
Rainfall	X+(1)	X+(1)	X+(1)	(2)	(2)	X	(2)	X+(2)	(2)	X+(2)
Soil type	(3)	(3)	(3)	(5)	(3)	(5)	(4)	X	X	(8)
Slope steepness	0	0	0	0	0	0	0	X	0	0
Slope length	0	0	0	0	0	(6)	(6)	X	(6)	0
Surface condition	*	*	*	*	*	X	X	X	X	*
Control measures	X	X	X	*	*	X	X	X	X	*
Distance to stream	(7)	(7)	(7)	(7)	(7)	(6)	(6)	X	N A	(6)
Percent disturbed	X	X	X	X	X	X	X	X	X	X

X = Given by author of referenced source

(1) = Supplemented by raw data obtained from author

(2) = US Weather Bureau TP 40 and Wischmeier rainfall distribution

(3) = USDA Soil Conservation Service (SCS), Montgomery County, Md., Office

(4) = SCS, Harrisburg, Pa.

(5) = SCS, Fairfax Co., Va.

(6) = Estimated from site map/diagram

(7) = Estimated from SCS maps

(8) = Estimated by MITRE after consultation with SCS San Francisco office and comparison with other California soil data

N A = Not applicable; measurement taken at end of experimental plot

* = When not stated by author, surface condition was assumed to be raw cut or dense compaction with no control measure

0 = Estimated by MITRE from engineering judgement based on type of co..-struction in given terrain

TABLE IV-4

PRESENTATION OF BASIN DATA AND YIELDS PREDICTED BY UNIVERSAL SOIL LOSS EQUATION

Case, Location and Date	Watershed Area acres	% Area Disturbed by Constr	Distance to Stream feet	Precip. inches	R*	K	L feet	S %	LS	Yield (Observed) tons/acre	Yield (Predicted)** tons/acre	Ratio
Yorke & Davis Rock Creek - Anacostia												
Lutes Run												
7/20/67	301	9.6	300	1.42	28.7 -S	.37	200	6.5	1.1	2.5	11.7	4.6
8/19/67		9.6		1.42	17.1 -S					1.18	6.95	5.9
10/25/67		8.3		1.14	23.3 -S					1.28	9.48	7.4
3/17/68				1.49	4.17-S					2.31	1.69	0.73
5/27/68				2.76	9.07-S					2.31	3.69	1.6
7/02/68				2.03	32.6 -S					4.08	13.23	3.2
Bel Pre Creek												
11/28/66	1082	13.9	400	1.29	5.8 -S	.35	200	5.4	.84	0.36	1.71	4.7
5/07/67		13.8		2.01	14.1 -S					1.11	4.15	3.7
7/20/67		13.6		.96	4.2 -S					0.39	1.24	3.2
8/03/67		13.4		2.28	30.0 -S					3.58	8.82	2.5
8/24-25/67		13.4		3.69	28.2 -S					3.07	8.29	2.7
6/19-20/68		9.7		1.04	17.1 -S					1.00	4.98	5.0
7/2-3/68		9.7		1.36	14.7 -S					0.50	4.32	8.6
Manor Run												
11/28/66	646	8.0	300	1.29	5.8 -S	0.36	200	7.1	1.2	0.25	2.51	10.2
5/07/67		10.8		1.98	14.1 -S					3.8	6.10	1.6
8/03/67		11		2.18	30.0 -S					6.15	12.96	2.1
8/24-25/67		11		3.28	28.2 -S					19.44	12.18	0.63
6/19-20/68		11.8		0.88	17.1 -S					6.49	7.38	1.1
7/2-3/68		11.8		1.36	14.7 -S					3.04	6.36	2.1

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* R value computed by:
S = Single storm method (Reference 3-4 and 3-5)
A = Average annual method (Reference 3-3 and 3-6)
Q = Quarterly method (Average annual method modified to quarters by Wischmeier's distribution curves. Reference 3-3.)

** By Universal Soil Loss Equation

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TABLE IV-4

(contd.)

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
	acres		feet	inches			feet	%		tons/acre	tons/acre	
Vice, Guy, Ferguson (3-14)												
Scott Run												
May - Jun '61	2900	8.6	300	7.0	50.0 -Q	0.4	250	10.0	2.5	19.4	43.0	2.2
Jul - Sep '61		10.7		11.5	100.0 -Q					18.1	86.0	4.8
Oct - Dec '61		10.3		7.25	30.0 -Q					7.84	25.8	3.3
Jan - Mar '62		10.7		9.5	12.0 -Q					11.0	10.3	0.93
Apr - Jun '62		10.5		8.5	58.0 -Q					27.3	49.9	1.8
Jul - Sep '62		9.8		4.25	100.0 -Q					0.14x	86.0	613.0x
Oct - Dec '62		8.4		11.5	30.0 -Q					10.5	25.8	2.5
Jan - Mar '63		5.5		9.5	12.0 -Q					20.9	10.32	0.49
Apr - Jun '63		3.8		9.25	58.0 -Q					21.6	49.9	2.3
Jul - Sep '63		3.6		12.5	100.0 -Q					3.2	86.0	18.8
Oct - Dec '63		2.4		9.25	30.0 -Q					16.6	25.8	1.6
Jan - Mar '64		2.1		10.5	12.0 -Q					17.3	10.3	0.6
Apr - Jun '64		1.4		7.75	58.0 -Q					16.0	49.9	3.1
Jul - Sep '64		1.9		7.00	100.0 -Q					1.82†	86.0	47.3

x Only one storm reported on during quarter.
† Cover effects during the end of construction may have reduced this value.
(A) Sed. data is adjusted for non-const. sources - estimated by authors.

YEARLY SUMMATIONS FOR ABOVE QUARTERLY DATA FOR SCOTTS RUN

1961 May - Dec	2900	10.0	300	25.75	180.0 -A	0.4	250	10.0	2.5	44.1	155	3.5
1962		9.8		33.75	200.0 -A					50.4	172	3.4
1963		3.8		40.5	200.0 -A					66.4	172	2.6
1964 Jan - Sep		1.8		25.75	170.0 -A					34.2	146	4.3
(3-16) Guy - Storm Agnes 6/72	49.1	49.1	500	13.84	283.0 -S	0.3	300	6.0	1.15	20.4	97.5	4.8

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TABLE IV-4

(contd.)

Case, Location and Date	Watershed Area acres	% Area Disturbed by Constr	Distance to Stream feet	Precip. inches	R*	K	L feet	S %	LS	Yield (Observed) tons/acre	Yield (Predicted)** tons/acre	Ratio
Guy (3-15)												
Kensington												
Jul - Sep '59	58	17.2	200	1.7	100.0 -Q	0.41	250	6.0	1.05	12.8	43.0	3.4
Oct - Dec '59		17.2		2.14	30.0 -Q					8.0	12.9	1.6
Jan - Mar '60		17.2		1.5	12.0 -Q					8.7	5.2	0.6
Apr - Jun '60		17.2		3.1	58.0 -Q					18.4	25.0	1.4
Jul - Sep '60		17.2		8.4	100.0 -Q					45.9	43.0	0.94
Jan - Mar '61		8.6		0.4	12.0 -Q					1.2	5.2	4.3[x]
Apr - Jun '61		5.2		2.12	58.0 -Q					15.0	25.0	1.7
Jul - Sep '61		1.7		1.2	100.0 -Q					6.3	43.0	6.8
Oct - Dec '61		1.7		0.5	30.0 -Q					4.4	12.9	2.9
Single Storm												
8/04/60	58	17.2	200	1.8	48.0 -S					25.6	20.7	0.8
(3-19) **Reed-Harrisburg**												
Road Const. May - Aug '70	490	3.1	500		58.5 -Q	0.22	300	5.0	0.95	2.7	12.2	4.6
Pond Const. Aug - Dec '70	490	2.2	100		58.5 -Q	0.22	350	2.0	0.4	1.6	5.1	3.2
(3-18) Diseker & Richardson												
Georgia Plot 1	0.16	69.0	0	45.28	250.0 -A	0.24	206	71.0	33.0	289.0	1973.0	6.8
Plot 3	0.21	67.0		40.1	250.0 -A	0.24	365	40.0	24.0	129.0	1286.0	10.0
Plot 5	0.15	78.0		40.1	250.0 -A	0.24	296	100.0	65.7	196	3941.0	20.0
Plot 2	0.27	67.0		45.78	250.0 -A	0.24	225	83.0	43.3	120.6	2598.0	21.6
Plot 4	0.30	67.0		40.1			310	30.0	12.6	42.8	756.0	17.7
Plot 6	0.23	65.0		40.0			321	91.0	61.0	110.1	3660.0	33.3

[x] Only one storm reported on during quarter.

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TABLE IV-4

(contd,)

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
	acres		feet	inches			feet	%		tons/acre	tons/acre	
Reeder I-40 (3-17)												
7/13-9/16 '71	24	83.0	800	10.01	126.0 -Q	0.45	100	20.0	4.2	67.0	238.0	35.3
9/16-2/6 '72				14.8	57.0 -Q					97.0	108.0	11.2
2/6-4/24 '72				5.85	24.0 -Q					0.68	45.4	66.7
4/24-5/8 '72				2.31	6.0 -Q					51.0	113.0	2.2
5/8-6/9 '72				4.28	21.0 -Q					58.5	387.0	6.8
6/9-7/11 '72				5.78	60.0 -Q					128.5	1134.0	8.8
7/11-8/15 '72				7.09	78.0 -Q					75.0	1474.0	19.7
Colma Creek (3-20) (Knott) Gaging Station												
1969	6900	14.0	2500	28.2	76.13	0.48	215	7.0	1.25	61.4 85.2	63.5	0.74* 0.53
1970		8.0	2500	19.6	76.13					41.0 66.1	44.0	1.11 0.68
1967				30.75	76.13					147.0	45.7	0.31

* Top number is author estimate of sediments due to construction activity (not available for 1967); lower number is total measured sediment.

Case, Location and Date	Watershed Area	% Area Disturbed by Constr	Distance to Stream	Precip.	R*	K	L	S	LS	Yield (Observed)	Yield (Predicted)**	Ratio
Single Storms												
Hickey Blvd. 2/11/69	736	42.0	500	1.2	7.6	4.8	215	7.0	1.25	1.21	4.56	3.8
Colma Creek gaging St. 2/11/69	6900	14.0	2500	1.2	7.6					1.5	4.38	2.9
Hickey Blvd. 1/20/69	736	42.0	500	0.5	1.1					0.56	0.67	1.2
Colma Creek 1/20/69	6900	14.0	2500	0.5	1.1					0.68	0.66	0.96
Avalon 1/20/69	211	20.0	500	0.1	1.1					10.0	0.66	0.07

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sources such as weather records or Soil Conservation Service soil maps. In only one study, Diseker/Cartersville, Georgia, was all of the needed data reported, but this was a small experimental situation although located on an actual construction site.

3) Soils Data

Identification of soils were given by the authors for most of the case studies, but real distributions were given for only a few cases. For these, soil-type distribution data were obtained from the county office the U.S.D.A. Soil Conservation Service. Soil erodibility K factors were either obtained from the Soil Conservation Service and weighted according to the soil types present in the area, or they were estimated by comparison with similar soils.

4) Slope Steepness and Length

Construction slopes and slope length data were generally absent from the original studies. One notable exception was the highway roadcut study in Georgia. The Rock Creek study listed slopes for one year and these were assumed constant throughout the three-year study. In general slopes were assumed to average six percent for urban construction sites and ten percent for highways when no other data were given.

Lengths of slopes on construction sites were estimated, where appropriate, from site diagrams. Otherwise, an estimate of between 200 and 300 feet was made for urbanization construction, depending on the amount of construction in the basin and the basin size.

Slope length and steepness are combined into a composite term, LS, that can be read off a graph or determined by an equation. (22, 23) Both are normalized to a unit plot 72.6 feet long with a nine percent slope.

5) Sediment Control Practices

In most of the reports, sediment control practices were stated to be negligible. In others there may have been occasional use of hay bales or even more effective methods, but no data were given so all C and P values were assumed to equal 1.0.

6) Sediment from Non-Construction Sources

In some cases, especially in the larger basins, sediment yield data were adjusted to account for non-construction sediment sources. (This adjustment was made by the author of the Colma Creek study, which was in the largest of the drainage basins considered here). In other studies, it was assumed that all sediment came from construction activities. This was generally a reasonable assumption since these basins were usually quite small and the agricultural activity in them was minimal or nonexistent.

7) Distance to Stream; Percent Area Disturbed

Distance between construction site and receiving stream where sediment measurements were taken was generally estimated from site diagrams or maps. Since the Diseker/Georgia sediment measurements were made at the lower end of the disturbed area, data from this important source could not be applied in establishing a delivery ratio based on distance to stream.

The area disturbed by construction was given by the author in all case studies. This parameter varied during the period of construction activity, and the variation with time is given for most of the studies. From this information, the percent of the watershed disturbed by construction was computed. Both the distance parameter and the percent area disturbed were needed for estimating to delivery ratio.

8) Rainfall Data

Rainfall and total precipitation information were given in several forms. The rainfall factor, R, was evaluated by different methods according to the form of the data. Most of the studies (Scott Run, Kensington, Harrisburg, Georgia, North Carolina, and Colma Creek) gave continuous data over periods from one month to a year. The R value for these was computed by the average annual method using the distribution curves and iso-erodent map given by Wischmeier and Smith. (22) For single storms where storm hydrographs were available (Rock Creek, Reston, and one storm at Kensington), R was computed by the method developed by Wischmeier. (24, 25) For other single storms where only total rainfall was available, R values were estimated using the equations given by Hotes _et_ _al_., (23) which require only total rainfall and storm duration. The latter was estimated; 24 hours most frequently gave the best results.

Rainfall data available from the Rock Creek studies of Yorke and Davis were sufficiently detailed to permit evaluation of the R factor by both of the single-storm methods referenced above. Predicted sediment yields based on both balues of R are presented and compared in the subsequent presentation of data. Also, rainfall data for the Scott Run studies of Vice, Guy, and Richardson are sufficiently detailed to permit determination of separate R values for both quarterly and yearly periods. Predicted sediment yield values for these different-length periods are also compared in the following data presentation.

9) Presentation of Data Used to Fit Function; Sediment Yields Predicted by Universal Soil Loss Equation

The purpose of this section is to present the data used in fitting the source loading functions described in the following section. It is an attempt to relate these factors to the Houston area. Some of the data were subjected to two types of analyses before the loading functions were fitted.

-an analysis of predicted sediment yield based on different methods of computing the rainfall factor, R
-an analysis of predicted sediment yield for different seasons of the year.

Since both of these lines of analysis have implications for the accuracy of the loading functions, it is appropriate that they be discussed in connection with the basic data. The analysis of the effects of the methods for computing R is important since it determined the method that was subsequently used to evaluate this factor for the purpose of fitting the loading function.

Not all of the studies reported data in sufficient detail for these preliminary analyses. Only the Yorke and Davies studies of Rock Creek, Maryland, permit comparisons of different methods of computing R (after additional raw data were obtained from these authors). The Rock Creek studies and the Scott Run (Virginia) and Kensington (Maryland) studies by Guy, Vice, and Ferguson permitted analysis of the effects of seasons.

The volume of data is large and its organization somewhat complex. The basic raw data for all case studies are presented in a single figure. Following this are two analytic figures. The first compares the effect of different methods for computing the rainfall factor on the predicted values of sediment yield, with all other factors held constant. The second shows the effects of season of the year on predicted yields.

Summary of Data from All Case Studies. The basic data from all case studies used in fitting the loading functions are tabulated in Table IV-4. These data are used in a variety of ways in the analyses that follow, and each such application does not, in general, present all of the information available for a given site, storm event, time interval, etc. The reader who wishes to know what data went into the estimates of sediment yield presented in subsequent analytical figures will find the comprehensive summary of data in Table IV-4 helpful.

In addition to basic data such as rainfall, size of construction area, slope lengths, sediment yield, etc., Table IV-4 also contains values of the various factors of the Universal Soil Loss Equation:

R	rainfall factor
K	soil factor
LS	slope-length factor

The computation of these factors is discussed earlier in this section. The computation of R values in Table IV-4 were made by the method of Wischmeier and Smith (22, 25) for single storms and by the method reported in Hotes et al. (23) for cases based on continuous records for quarterly or annual periods.

Method of Comparison: Ratio of Predicted-to-Observed Sediment Loss. (2) The basic parameter to be estimated by the loading functions is quantity of sediment reaching the receiving water per unit of area disturbed by construction. The unit was tons/acre in the original E.P.A. study (2), but will be presented as suspended solids (mg/l) from the SWMM runs. In order for a case study to be useful for developing loading functions, one or more measured values of this parameter must be reported. Such values may be for a single storm event or for defined time intervals.

As a means of coarsely assessing the effects of seasonal variations or of methods of computing the rainfall factor on the predictive capability of loading functions, the Universal Soil Loss Equation was used to "predict" the sediment loss for each storm event or time interval for which sediment-loss measurements were available. The results were compared with measured (or "observed") values, and a ratio of predicted/observed values computed. This ratio forms the basic unit of comparison used in this section of the report. A similar ratio based on "predicted" values from fitted loading functions is used in a later section for evaluating the accuracy of these functions. (A ratio value of 1.0 would indicate perfect agreement between predicted and observed yields).

The Universal Soil Loss Equation was chosen for these preliminary analyses because it appeared to be the most nearly applicable model available, prior to the development of actual loading functions based on the data at hand, but primarily because the investigators anticioated that the loading functions would be variations of this equation.

TABLE IV-5

TWO METHODS FOR ESTIMATING RAINFALL EFFECTS

					Based on R_1		Based on R_2	
Case, Location and Date	Precipitation inches	R_1 Ref. 22,25	R_2 Ref. 23	Yield (Observed) tons/acre	Yield (Predicted) tons/acre	Ratio Predicted/ Observed	Yield (Predicted) tons/acre	Ratio Predicted/ Observed
Locks & Davis Rock Creek-Anacostia								
Lutes Run								
7/20/67	1.42	28.7	9.4	2.5	11.7	4.6	3.84	1.5
8/19/67	1.42	17.1	9.4	1.18	6.95	5.9	3.84	3.3
10/25/67	1.14	23.3	8.0	1.28	9.48	7.4	3.26	2.5
3/17/68	1.49	4.17	16.7	2.31	1.69	0.73	6.77	2.9
5/27/68	2.76	9.07	53.7	2.31	3.69	1.6	21.85	9.5
7/02/68	2.03	32.6	20.7	4.08	13.23	3.2	8.42	2.1
Bel Pre Creek								
11/28/66	1.29	5.8	7.64	0.36	1.71	4.7	2.2	6.2
5/7/67	2.01	14.1	20.3	1.11	4.15	3.7	6.0	5.4
7/20/67	0.96	4.2	4.0	0.39	1.24	3.2	1.2	3.0
8/3/67	2.28	30.0	26.8	3.58	8.82	2.5	7.9	2.2
8/24-25/67	3.69	28.2	77.1	3.07	8.29	2.7	22.6	7.4
6/19-20/68	1.04	17.1	4.8	1.00	4.98	5.0	1.4	1.4
7/2-3/68	1.36	14.7	8.6	0.50	4.32	8.6	2.5	1.5
Manor Run								
11/28/66	1.29	5.8	7.64	0.25	2.51	10.2	3.3	13.2
5/7/67	1.98	14.1	19.6	3.8	6.10	1.6	15.5	2.1
8/3/67	2.18	30.0	24.3	6.15	12.96	2.1	10.4	1.7
8/24-25/67	3.28	28.2	59.5	19.44	12.18	0.63	25.6	1.3
6/19-20/68	0.88	17.1	6.3	6.49	7.38	1.1	2.7	0.42
7/2-3/68	1.36	14.7	8.6	3.04	6.36	2.1	3.7	1.2
					Average	3.8	Average	3.6

TABLE IV-6

COMPARISON OF THE EFFECTS OF SEASON VARIATIONS ON SEDIMENT YIELD

Case, Location and Date		Precip.	R/Method	Yield (Observed)	Yield (Predicted)	Ratio Predicted/ Observed
		inches		tons/acre		
			JANUARY - MARCH			
Lutes Run						
3/17/68		1.49	4.17-S	30	22	.73
Scott Run	'62	9.5	12 -Q	3475	3200	.93
	'63	9.5	12 -Q	3350	1651	.49
	'64	10.5	12 -Q	1040	619	.6
Kensington	'60	1.5	12 -Q	87.3	51.6	.6
	'61	.4	12 -Q	6	26	4.3
					Average	1.3
			JULY - SEPTEMBER			
Lutes Run						
7/20/67		1.42	28.7 -S	73	237	4.6
8/19/67		1.42	17.1 -S	34	201	5.9
7/02/68		2.03	32.6 -S	.53	172	3.2
Bel Pre Creek						
7/20/67		.96	4.2 -S	57	182	3.2
8/03/67		2.28	30.0 -S	519	1,279	2.5
8/24-25/67		3.69	28.2 -S	445	1,202	2.7
7/2-3/68		1.36	14.7 -S	53	458	8.6
Manor Run						
8/3/67		2.18	30.0 -S	437	920	2.1
8/24-25/67		3.28	28.2 -S	1380	865	0.63
7/2-3/68		1.36	14.7 -S	231	483	2.1
Scott Run	'61	11.5	100 -Q	4844	10,750	2.2
	'62	4.25	100 -Q	40	24,310	613*
	'63	12.5	100 -Q	480	9,030	18.8
	'64	7.0	100 -Q	100	4,730	47.3
Kensington	'59	1.7	100 -Q	128	430	3.4
	'60	8.4	100 -Q	459	430	0.94
	'61	1.2	100 -Q	6.3	43	6.8
8/4/60		1.8	48 -S	256	207	0.8
					Average	6.3

* One storm

Case, Location and Date		Precip.	R/Method	Yield (Observed)	Yield (Predicted)	Ratio Predicted/ Observed
		inches		tons/acre		
			APRIL - JUNE			
Lutes Run						
5/27/68		2.76	9.07-S	30	48	1.6
Bel Pre Creek						
5/7/67		2.01	14.1 -S	165	618	3.7
5/19-20/68		1.04	17.1 -S	106	528	5.0
Manor Run						
5/7/67		1.98	14.1 -S	266	426	1.6
6/19-20/68		0.88	17.1 -S	493	561	1.1
Scott Run						
May-June	'61	7.0	50 -Q	4,844	10,750	2.2
	'62	8.5	58 -Q	8,330	15,213	1.8
	'63	9.25	58 -Q	2,380	5,847	2.3
	'64	7.75	58 -Q	640	1,995	3.1
Guy-Agnes						
6/72		13.84	283 -S	492	2,351	4.8
Kensington	'60	3.1	58 -Q	184	250	1.4
	'61	2.12	58 -Q	44	75	1.7
					Average	2.5
			OCTOBER - DECEMBER			
Lutes Run						
10/25/67		1.14	23.3 -S	9.48	1.28	7.4
Manor Run						
11/28/66		1.29	5.8 -S	2.51	0.25	10.2
Scott Run						
Oct-Dec	'61	7.25	30 -Q	25.8	7.84	3.3
	'62	11.5	30 -Q	25.8	10.5	2.5
	'63	9.25	30 -Q	25.8	16.6	1.6
Kensington						
Oct-Dec	'59	2.14	30 -Q	12.9	8	1.6
	'61	0.5	30 -Q	12.9	4.4	2.9
					Average	4.2

Comparison of Two Methods for Computing R for Single Storms. The rainfall data for the Rock Creek/Anacostia River studies of Yorke and Davies were sufficiently complete when augmented by raw data from the EPA (2) to permit computation of the rainfall factor R needed in the Universal Soil Loss Equation by two different methods: one developed by Wischmeier and Smith and a newer procedure reported in 1973 by Hotes et al. The resulting values of R in Table IV-5 are designated as R_1 and R_2.

R- values were computed by both methods, and predicted sediment yield per acre during each storm was computed by the Universal Soil Loss Equation for each value of R. Results are given in Table IV-5.

To facilitate comparison, the ratio of predicted/observed yield was computed for each R-value, and these ratios were averaged for all storm events. Comparison of the two columns of ratios near the right hand side of the figure reveals considerable divergence in the results obtained from the two R-values, and these ratios were averaged for all storm events. Comparison of the two volumns of ratios near the right hand side of the figure reveals considerable divergence in the results obtained from the two R-values, although the averages of ratios are similar for the two methods: 3.8 for R_1 and 3.6 for R_2. The range of ratio values for R_1 is smaller than the range for R_2.

Although the smaller average value of ratios for R_2 might be interpreted to mean that R_2 provides a slightly more accurate prediction (in the sense that predicted values agree more closely when observed); the two averages were so close that the difference was considered not to be significant. Also, the scatter (range of ratio values) for R_1 was somewhat smaller than for R_2.

In view of these results, neither method was judged clearly preferable to the other. If the time distribution of rainfall during the storm is available, as in the Rock Creek studies, the R_1 approach is preferred by the E.P.A. If this information is not available, the R_2 approach should be used since it requires only a knowledge of total rainfall during the storm and an estimate of storm duration.

The R_1 procedure, based on the method of Wischmeier and Smith, was selected for subsequent analyses of single storm data, including the fitting of loading functions.

Effects of Seasons on Predictive Capability. Preliminary analysis of the predicted-to-observed ratios in Table IV-4 revealed a cyclic pattern with season for the four case studies reporting seasonal data. Relevant data from these four studies were abstracted and compiled in Table IV-6 show the season effect.

Predicted values of sediment yield rates for measures made during the winter were generally equal to or lower than the observed yield rates, while in the spring and fall the predicted values averaged three to five times higher than the observed, and in the summer averaged six to seven times higher. The average of predicted-to-observed ratios for the quarterly periods shown in Figure IV-6 are as follows:

Quarter	Ratio Average
January - March	1.3
April - June	2.5
July - September	6.5
October - December	4.2

The interpretation of these results is by no means clear. The apparent seasonal differences may indicate unusual rainfall patterns during the study periods or it may mean the distribution curves for these areas need adjustment. The Kensington study results may appear misleading because only selected storm results were reported, totaling less than one-half the yearly precipitation. Presumably most of the large storms are reported, since the results are similar to those from the other areas in the vicinity.

All of the case studies covered in Table IV-6 are located in close proximity to one another -- all lie in the Washington, D.C., metropolitan area. The results, therefore, cannot be considered generally applicable to other areas.

Selection and Fitting of Loading Functions. The endeavor to develop sediment yield loading functions began early in the E.P.A. study (2) with experiments in fitting established soil loss models to the available data, then comparing computed yields with observed to assess the fit. Models tested included established soil loss equations such as the Musgrave and the Universal Soil Loss Equation as well as some arbitrary functions proposed by the EPA investigators. The latter were of the general form of the Musgrave Equation: multiplicative factors raised to powers, but with the additional feature of additive constants.

From the standpoint of estimating observed sediment yields, the Universal Soil Loss Equation proved generally superior to the other forms tested, to the extent that the investigators decided to concentrate on modifying this basic equation to improve its fit to construction-related. Two types of modifications were evaluated.

One modification set the C and P values (cropping and erosion control factors) to unity, added a distance factor, D (average distance of overland travel from construction area to receptor stream), and fitted empirically-determined exponents to the three terrain related factors to produce a new equation of the form:

$$Y = RKL^{a}S^{b}D^{c}$$

where Y is sediment yield in tons/acre and the other factors are as they appear in the universal and the Musgrave, and with its exponential modification to slope and slope length, appears to provide the flexibility needed for adaptation to construction conditions. However, when the exponents were fitted to observed data by the method of least squares, the resulting function gave predicted yields that compared less closely with observed yields than did the predictions of the Universal Soil Loss Equation. This result is ambiguous at best, since the above equation with three arbitrarily-fitted constants should theoretically have given at least as close a fit as the deterministic Universal Soil Loss Equation. This ambiguity was attributed to sparse data of unknown reliability, and the above equation was abandoned in favor of a simpler formulation bearing a close relation to the Universal Soil Loss Equation.

The simpler form of model tested next was the basic Universal Soil Loss Euqation adjusted by a "delivery ratio" to account for the difference in total sediment yield at the site and the amount reaching the receptor stream. The concept of a delivery-ratio has been suggested and applied by several investigators, (26, 27, 13) but generally the forms of this factor and their application to construction site data have not previously been investigated. The resulting equation is of the form:

$$Y = R\ K\ LS\ C\ P\ (Z)^{x}$$

where $(Z)^{x}$ is the delivery ratio and other elements are the elements of the Universal Soil Loss Equation as defined above.

Two intuitively relevant parameters that could be evaluated for most of the case studies were chosen as the Z variable in the delivery ratio:

D - distance between construction site and receptor stream, in feet

%A - percent of drainage basin exposed by construction

Observed values for these two parameters were used in obtaining a least square fit for the exponent x. (The factors C and P were again set to unity but were retained in the resulting equation). The resulting functions were obtained:

$$Y = R\ K\ LS\ C\ P\ D^{-0.22}$$

$$Y = R\ K\ LS\ C\ P\ (\%A)^{-0.51}$$

These two equations were considered to be the best sediment loading functions readily obtainable from the abailable data.

Results obtained by applying these loading functions to the data from all case studies are presented in Table IV-7. Sediment yield rates obtained from each function are expressed as ratios to the observed rates. To facilitate comparison, these ratios are displayed together with the predictions obtained for the Universal Soil Loss Equation and with values of certain critical parameters that enter into the yield calculations.

Characteristics of Loading Functions Predictions. The sediment yield rate predicted by an equation such as the Universal Soil Loss Equation refers to the condition at the boundary of the area in question, whether this contains agricultural lands or construction. The predicted rate might logically be expected to be lower than the rate observed some distance away in a watercourse. This expectation is borne out in the Table IV-7 data which shows predicted/observed ratios for the Universal Equation as generally greater than unity, the average value being 7.37. In contrast, L. D. Meyers (13) reports a value very close to unity (0.98) at the foot of an experimental plot. This difference is probably due, in part, to the effects of intervening terrains.

The improvement in predictive capability of the two fitted loading functions relative to the Universal Equation for construction sites is indicated by the generally lower values of the predicted/observed ratio values for the loading functions. The average values over all case studies are as follows:

	Average Value of Ratio
Universal Soil Loss Equation	7.37
Loading function with adjustment for distance	1.33
Loading function with adjustment for percent of watershed area disturbed	1.78

The reader is reminded that the above values are averages of ratios of predicted (or estimated) yields in tons/acre to observed yields in the same unit. Thus a ratio of 1.00 indicates that the estimated and observed values are equal.

Averages, Standard Deviations, and Frequency Distributions of Predicted/Observed Ratios. It was with some reluctance that the EPA writers reported summary statistics (acreages, ranges, standard deviations) of the yield ratios because of difficulties in interpretation of these statistics and the potential for misapplication.

One problem of interpretation is in the meaning of an average of ratios. Given the method of computing ratios used in the E.P.A. report, the values cannot be negative. Any estimate less than the corresponding observed yield produces a ratio value between zero and unity; any estimate greater than the observed yield produces a value greater than unity--sometimes much greater since it is not constrained by an upper bound as in the case of the less-than-observed ratio. If, for example, an estimated value is one-fifth the observed, the ratio is 0.20. If it is five times greater, the value is 5.00. The average of these two ratio values is 2.60, implying that "on the average" the predicted values are 2.6 times greater than observed. From one standpoint, the average appears unduly weighted by the large ratio values when the estimate exceeds the observed value. This weighting effect is similarly reflected in measures of scatter such as the range or standard deviation.

With the above observations caveats, the summary statistics of the yield ratios for values predicted by the Universal Soil Loss Equation and the two loading functions are given in Table IV-8. In presenting these results, the E.P.A. authors emphasized that the statistics have not been subjected to thorough analysis evaluation, and therefore are not recommended for use in testing of hypotheses concerning closeness of fit of predicted-to-observed yields or similarity among results predicted by the three methods.

Perhaps more revealing and more easily interpreted than the summary statistics are the frequency distributions of ratios presented in Figure IV-1. As expected, the predictions by the Universal Soil Loss Equation tend generally to overestimate the sediment yield, because of the effects of terrain between disturbed area and point of measurement.

The frequency distribution for the loading function adjusted for distance between disturbed area and receptor stream exhibits a definite clustering near the ratio value of 1.00, and shows a general symmetry about this value. Instead of tailing off at either extreme, however, it displays a clustering at the extremes. In this distribution, approximately 53 percent of the yield ratios lie between values of 0.50 and 1.50, implying that 53 percent of the estimated yields fell within ± 50 percent of the observed. Also, about 90 percent of the values lie between 0.20 and 5.00, implying that 90 percent of the estimated yields fall within one-fifth and five times the observed value. The median lies in the interval 0.67-1.00. These percentage intervals and ranges are based on the case studies of the EPA report, and should not be considered universally applicable.

TABLE IV-7

COMPARISON OF FITTED FUNCTIONS

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
(3-13) Yorke & Davis Rock Creek- Anacostia											
Lutes Run											
7/20/67	S	301	9.6	300	2.5	11.7	4.6	3.3	1.3	3.6	1.45
8/19/67			9.6		1.18	6.95	5.9	2.0	1.7	2.2	1.86
10/25/67			8.3		1.28	9.48	7.4	2.7	2.1	3.2	2.5
3/17/68					2.31	1.69	0.73	0.5	0.21	0.8	0.34
5/27/68					2.31	3.69	1.6	1.1	0.46	1.8	0.76
7/02/68					4.08	13.23	3.2	3.8	0.92	6.2	1.52
Bel Pre Creek											
11/28/66	S	1082	13.9	400	0.36	1.71	4.7	0.47	1.3	0.44	1.23
5/07/67			13.8		1.11	4.15	3.7	1.1	0.99	1.1	0.97
7/20/67			13.6		0.39	1.24	3.2	0.33	0.85	0.33	0.85
8/03/67			13.4		3.58	8.82	2.5	2.4	0.66	2.4	0.67
8/24-25/67			13.4		3.07	8.29	2.7	2.2	0.72	2.2	0.72
6/19-20/68			9.7		1.00	4.98	5.0	1.3	1.34	1.6	1.57
7/2-3/68			9.7		0.50	4.32	8.6	1.2	2.3	1.4	2.7
Manor Run											
11/28/66	S	646	8.0	300	0.25	2.51	10.2	0.73	2.9	0.88	3.53
5/07/67			10.8		3.8	6.10	1.6	1.7	0.46	1.7	0.46
8/03/67			11.0		6.15	12.96	2.1	4.9	0.80	3.8	0.62
8/24-25/67			11.0		19.44	12.18	0.63	3.5	0.18	3.7	0.19
6/19-20/68			11.8		6.49	7.38	1.1	2.0	0.31	2.0	0.31
7/2-3/68			11.8		3.04	6.36	2.1	1.8	0.60	1.8	0.60

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TABLE IV-7

(contd.)

						By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
Guy (3-15)											
Kensington											
Jul - Sep '59	Q	58	17.2	200	12.8	43.0	3.4	64.8	1.06	10.2	0.80
Oct - Dec '59			17.2		8.0	12.9	1.6	4.0	0.50	3.0	0.37
Jan - Mar '60			17.2		8.7	5.2	0.6	1.7	0.44	1.2	0.14
Apr - Jun '60			17.2		18.4	25.0	1.4	8.1	0.44	6.1	0.33
Jul - Sep.'60			17.2		45.9	43.0	0.94	13.3	0.29	10.1	0.22
Jan - Mar '61			8.6		1.2	5.2	4.3x	1.6	1.34	1.7	1.4
Apr - Jun '61			5.2		15.0	25.0	1.7	7.9	0.53	109.5	7.3
Jul - Sep '61			1.7		6.3	43.0	6.8	13.6	2.12	32.7	5.2
Oct - Dec '61			1.7		4.4	12.9	2.9	4.0	0.90	9.7	2.2
Single Storm											
8/4/60	S	58	17.2	200	25.6	20.7	0.8	5.2	0.25	3.9	0.19
(3-19) Reed-Harrisburg											
Road Const.											
May - Aug '70	Q	490	3.1	500	2.7	12.2	4.6	3.2	1.17	7.0	2.6
Pond Const.											
Aug - Dec '70	Q	490	2.2	100	1.6	5.1	3.2	1.9	1.16	33.6	21.0
(3-18) Diseker & Richardson											
Georgia Plot 1	A	0.16	69.0	0	289.0	1973.0	6.8	3266.0	Not Applicable	225.0	0.78
Plot 3	A	0.21	67.0		129.0	1286.0	10.0	2167.0		151.0	1.17
Plot 5	A	0.15	78.0		196.0	3941.0	20.0	6507.0		423.0	2.16
Plot 2	A	0.27	67.0		120.6	2598.0	21.6	2605.0		305.0	2.53
Plot 4	A	0.30	67.0		42.8	756.0	17.7	608.0		42.8	1.00
Plot 6	A	0.23	65.0		110.1	3660.0	33.3	3017.0		216.0	1.96

x Only one storm reported on during quarter.

TABLE IV-7
(contd.)

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
Vice, Guy, Ferguson (3-14)											
Scott Run											
May - Jun '61	Q	2900	8.6	300	19.4	43.0	2.2	12.2	0.63	14.2	0.73
Jul - Sep '61			10.7		18.1	86.0	4.8	24.8	1.37	25.9	1.43
Oct - Dec '61			10.3		7.84	25.8	3.3	7.4	0.94	7.8	1.0
Jan - Mar '62			10.7		11.0	10.3	0.93	3.0	0.27	3.1	0.28
Apr - Jun '62			10.5		27.3	49.9	1.8	13.9	0.51	14.7	0.54
Jul - Sep '62			9.8		0.14[x]	86.0[x]	613.0[x]	24.5	174.8[x]	27.0	191.4[x]
Oct - Dec '62			8.4		10.5	25.8	2.5	7.5	0.71	8.8	0.84
Jan - Mar '63			5.5		20.9	10.32	0.49	2.9	0.14	4.4	0.21
Apr - Jun '63			3.8		21.6	49.9	2.3	14.3	0.66	25.1	1.16
Jul - Sep '63			3.6		3.2	86.0	18.8	17.2	5.36	31.4	9.8
Oct - Dec '63			2.4		16.6	25.8	1.6	7.6	0.46	16.9	1.02
Jan - Mar '64			2.1		17.3	10.3	0.6	2.9	0.17	7.1	0.41
Apr - Jun '64			1.4		16.0	49.9	3.1	14.1	0.88	41.8	2.61
Jul - Sep '64			1.9		1.82[§]	86.0	47.3	24.6	13.49	62.1	34.1
YEARLY SUMMATIONS FOR ABOVE QUARTERLY DATA FOR SCOTTS RUN											
1961 May - Dec	A	2900	10.0	300	44.1	155.0	3.5	44.1	1.0	48.5	1.1
1962			9.8		50.4	172.0	3.4	48.9	0.97	53.4	1.06
1963			3.8		66.4	172.0	2.6	49.1	0.74	86.3	1.3
1964 Jan - Sep			1.8		34.2	146.0	4.3	42.1	1.23	109.4	3.2
(3-16) Guy - Storm Agnes 6/72	S	49.1	49.1	500	20.4	97.5	4.8	28.6	1.4	13.3	0.65

[x] Only one storm reported on during quarter.

[§] Cover effects during the end of construction may have reduced this value

(A) Sed. data is adjusted for non-const. sources - estimated by authors.

TABLE IV-7

(contd.)

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	By Universal Soil Loss Equation		By Loading Function Adjusted For Distance to Stream		By Loading Function Adjusted For % Area Disturbed	
						Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed	Yield (Predicted)	Ratio Predicted/ Observed
		acres		feet	tons/acre						
(3-17) **Reeder I-40**											
7/13-9/16 '71	Q	24.0	83.0	800	67.0	238.0	3.5	54.7	0.82	25.0	0.37
9/16-2/6 '72					97.0	108.0	1.1	24.8	0.26	11.3	0.12
2/6-4/24 '72					0.68	45.4	66.7	10.4	15.3	4.8	7.0
4/24-5/8 '72					51.0	113.0	2.2	26.0	0.51	11.9	0.23
5/8-6/9 '72					58.5	387.0	6.8	88.9	1.52	40.6	0.69
6/9-7/11 '72					128.5	1134.0	8.8	261.	2.0	119.	0.93
7/11-8/15 '72					75.0	1474.0	19.7	339.	4.5	155.	2.03
(3-20) **Colma Creek** **(Knott)**											
Gaging Station											
1969	A	6900	14.0	2500	61.4[x] 85.2	45.7	0.74[x] 0.53	11.1[x] 15.3	0.18	16.0[x] 22.1	0.26
1970	A		8.0		41.0 66.5	44.0	1.11 0.68	7.8 12.6	0.19	15.2 24.6	0.37
1967	A		NA		147.0	45.7	0.31				

[x] Top number is author estimate of sediments due to construction activity (not available for 1967); lower number is total measured sediment.

Case, Location and Date	Method of Computing R	Watershed Area	% Area Disturbed by Constr	Distance to receptor stream	Yield (Observed)	USLE Yield (Predicted)	USLE Ratio Predicted/ Observed	LF Distance Yield (Predicted)	LF Distance Ratio Predicted/ Observed	LF % Area Yield (Predicted)	LF % Area Ratio Predicted/ Observed
Single Storms •											
Hickey Blvd. 2/11/69	S	736	42.0	500	1.21	4.56	3.8	1.3	1.1	0.7	0.56
Colma Creek gaging St. 2/11/69	S	6900	14.0	2500	1.5	4.38	2.9	0.8	0.52	1.3	0.75
Hickey Blvd 1/20/69	S	736	42.0	500	0.56	0.67	1.2	0.2	0.4	0.1	0.18
Colma Creek 1/20/69	S	6900	14.0	2500	0.68	0.66	0.96	0.1	0.17	0.2	0.25
Avalon 1/20/69	S	211	20.0	500	10.0	0.66	0.07	0.3	0.03	0.2	0.02
AVERAGE OF RATIO VALUES FOR ALL CASE STUDIES							7.37		1.33		1.78

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TABLE IV-8

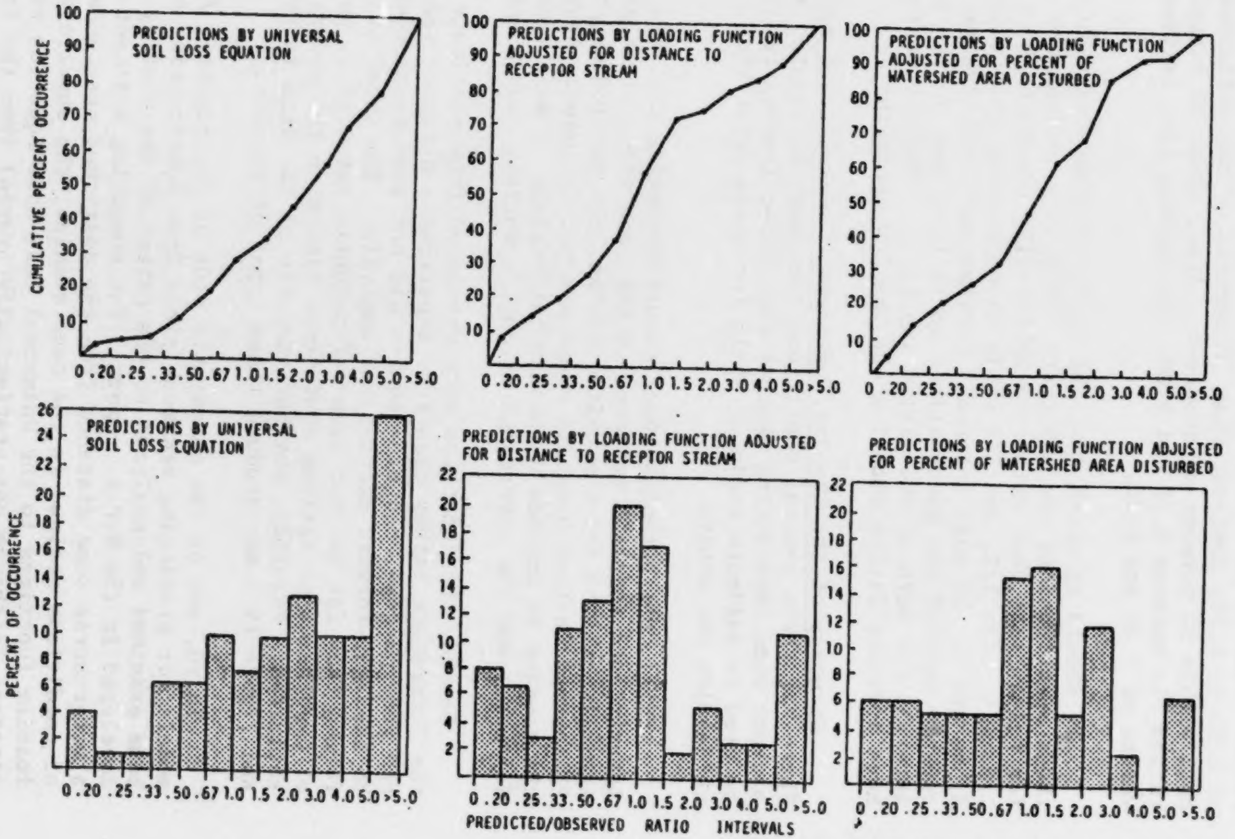
MEANS AND STANDARD DEVIATIONS OF PREDICTED/OBSERVED RATIOS OBTAINED BY THREE ESTIMATING PROCEDURES

	By Universal Soil Loss Equation	By Loading Function Adjusted for Distance to Stream	By Loading Function Adjusted for % Area Disturbed
Average of All Ratio Values*	7.37	1.33	1.78
Standard Deviations	11.20	2.23	3.09
Number of Observations* in above statistics	53	47	53

*For Scott Run, only annual averages were used, and the storm during quarter of July-September 1962 was excluded. For Colma Creek, only single storm results were used.

FIGURE IV-1

PERCENT FREQUENCY DISTRIBUTIONS OF PREDICTED/OBSERVED RATIOS



(NOTE: These distributions are based on a larger number of ratio values than the statistics in Exhibit 20, since quarterly and yearly estimates are included in the histograms.)

The function adjusted for percent of basin area disturbed by construction also exhibits a clustering about the ratio value of 1.0. The distribution appears generally symmetric about this value. Some 30 percent of the values lie within the ratio range of 0.50 to 1.50, implying that 30 percent of the estimated values fall within 50 percent of observed. Also, about 84 percent of the ratios lie between 0.20 and 5.00. The median lies between ratio values of 1.01 and 1.50.

It should be noted that the ratio intervals used in forming these distributions are arbitrary and highly non-uniform. Intervals for values less than unity are arbitrarily based on the factions 1/5, 1/4, 1/3, 1/2, and 2/3 while those greater than unity are 1.5, 3, 4, and 5. If unit intervals between zero and five had been used, roughly half of the observations would have been in the zero-one interval for both of the fitted functions. This arrangement would have provided little detail about the low estimates.

Accuracy of the Loading Functions; Generality of Application. (2) There are three general conditions that must be weighed and taken into account when considering whether the fitted loading functions should be used to estimate sediment yield for areas other than those used to develop the study.

First, the potential user should recognize that the soil type, terrain, and rainfall patterns of the case study sites are not entirely general for the United States. In particular, the Great Plains and Western Mountain areas are not included. Nevertheless, the studies do include a substantial variety of soil types and terrain features, and the importance of such a variety should not be minimized.

Second, the functions were developed from available data from the literature rather than from experiments designed specifically for this purpose, and the results did not lend themselves readily to straight-forward statistical analysis. The level of analysis performed thus far has not been sufficiently detailed to permit testing of hypotheses or setting confidence limits on the accuracy of estimates. Possibly, further analysis of the data in Table IV-7 and Figure IV-1 may produce these types of results.

Third, and on the optimistic side of the picture, few if any models for predicting sediment yield from construction sites have been examined and analyzed to the extent of the loading functions developed in the E.P.A. report. For computing sediment reaching a watercourse some distance from the disturbed area under the range of conditions defined in the case studies, the superiority of these loading functions to the Universal Soil Loss Equation seems intuitively apparent (although not statistically proven) from the frequency distributions in Figure IV-1.

In Summary

It is concluded that the loading functions provide the best available means for predicting the sediment yield from a construction site, in the absence of specific yield data for that site. This conclusion is based on an extensive yield data for that site. This conclusion is based on an extensive review of the literature as well as the foregoing analysis of data. Although no solid statistical basis has been developed for assessing the accuracy of their estimates, some general indications of the relation of estimated yields to observed yields may be drawn from the frequency distributions of Figure IV-1.

Recommendations for Improved Loading Functions. Since the fitted loading functions have been empirically derived from a rather small data set, they should be subject to further testing, preferably in areas of the midwest and central U.S. from which no data were obtained. In view of the observed impact of season on sediment yield, it appears important to obtain sufficient data to permit treating season effect as a separate variable.

It would be advisable either to design and carry out a series of experiments for this purpose or to locate similar experiments now underway and to determine which factors necessary to the soil loss equations are missing from those projects. Such data could then be collected in conjunction with the ongoing studies in order to eliminate the need for a large number of estimations.

Some of the data that should be gathered in future studies include:

- Accurate site descriptions including areas and timing of soil exposure, slope length, slope steepness, and amount of internal drainage
- Position of construction with respect to stream
- Character of land between stream and site including slope, cover, and potential sediment traps
- Continuous monitoring of both rainfall and sediment flow
- Information on other sediment sources in the basin
- Runoff and sediment data from control basins unaffected by construction

How to Use the Loading Functions

Since both of the loading functions developed here are modifications of the Universal Soil Loss Equation, their use essentially represents a manipulation of the results obtained by applying this equation to a given area. If the Universal Soil Loss Equation is used to estimate the sediment loss for a given area disturbed by construction operations, the loading function can be used to modify this estimate to obtain a more accurate estimate of the quantity of soil that will enter a receptor waterbody located a distance from the disturbed area.

Comments on Use of the Universal Soil Loss Equation

To the potential user of the Universal Soil Loss Equation for the purpose of obtaining inputs to the loading functions presented here, the following comments, are offered concerning evaluation of certain factors of the equations.

R-Factor (Rainfall)

If sufficiently detailed precipitation and hydrographic data are available, the "single-storm" method may be used. If not, the "average annual" method may be used.

The importance of seasonal effects on predictive capability of loading functions has been discussed in a previous subsection. When the average annual method is used, it is possible to account (to some degree) for seasonal variations in rainfall.

C-Factor (Cropping or Ground Cover)

In all of the cases used to fit loading function, the assumption was made that the soil was denuded and possibly subsoils were exposed. Since there was no cover crop, the C-Factor was assigned a value of "1". These same conditions will probably occur at any construction site, and a value of "1" used for C.

P-Factor (Erosion Control Practice)

P represents the reduction in soil loss by use of control measures. In fitting the loading functions, a value of "1" was assigned to P, corresponding to no control measures. It is suggested that the user also assign this value to P when no control measures, or measures of undetermined efficiency, are used. When measures of known and proven efficiency are used, P may appropriately be assigned the value of its efficiency. (Thus, if the control measure reduced soil loss to 60 percent of the loss if no control were employed, P would have a value of 0.60).

Estimation of Soil Loss by Use of Loading Functions - A Numerical Example

When an estimate of soil loss from a construction area has been obtained by use of the Universal Soil Loss Equation, it is then adjusted by means of the "delivery-ratio" portion of the loading function. This was done as follows:

The distance between the lowest part of the construction site and the receiving stream is known, this distance, expressed in feet, was used in the equation:

$$M = Y\ A\ D^{-0.22}$$

where: M is tons of soil delivered to stream

U is soil loss in tons/acre, as estimated by the Universal Soil Loss Equation

A is size of area disturbed by construction in acres

D is distance from construction site to stream

As an example, assume that a 20-acre site within a 200-acre watershed is denuded or otherwise disturbed by construction. The Universal Soil Loss Equation predicts a soil loss rate of 25 tons per acre over the estimated period during which the soil is disturbed. If the average distance between the lower boundary of the site (from which drainage will occur) and the receiving stream is 400 feet, then the estimated amount of soil lost to the stream will be:

$$M = (25)\ (20)\ (400)^{-0.22}$$

$$= 134 \text{ tons}$$

It is recommended that the function involving distance-to-stream be used when data are available, since this function gave better fit of estimated to observed soil losses.

Selected Methodology

For the preliminary assessment of the impact of construction activities it was decided to utilize the loading function based on the delivery ratio theorem rather than the disturbed area of the watershed. The delivery ratio function is preferable in this area because for the most part the percentage of the watershed that will be distributed at one time is very small and the delivery ratio better fits the known data as compared to the percent disturbed methodology. The stormwater Management Model development by the Environmental Protection Agency uses a delivery ratio formula and a standard set of routines. The subcatchment information has already been tabulated for Task 1 (Preliminary Assessment of Urban Runoff Impact) and the only additional work to utilize this computerized methodology consists of computing the erosion cards for each of the subcatchments and supplying the universal soil loss equation information to the computer. The computerized function will be used to develop the construction activity loads for all four of the specified years. A sample of the form of the output from the computer run is included with this report (Table IV-9 -- Sample of Erosion printout from the Stormwater Management Model Manual). In column four the suspended solids with construction activities are printed out in a time varying sequence and in column 11 the suspended solids without the erosion are printed out; by comparing column four with column 11 the volume of construction loads on the individual subcatchment can be determined.

Dredging Activities

This task quantifies the impacts of dredging and disposal in the H-GAC study area. The objectives were to: 1) identify areas impacted significantly by suspension and resuspension attributable to dredging and disposal activities, 2) project the loadings by BOD_5, COD, nutrients, and heavy metals from dredging and disposal operations, and 3) describe the physical, chemical and biological effects of dredging and disposal within the study area.

To achieve these objectives several subtasks were performed historical dredging and disposal records from the Corps of Engineers, Galveston District, were obtained and analysed to estimate volumes of dredged material and the frequency of dredging in channels of the study area. Projections of future volumes were made by assuming that all channels will be enlarged to fully authorized dimensions. Historical dredging records were also used to determine the types of dredging and disposal operations utilized in the study area. Data was collected on the physical and chemical characteristics of the sediments in the channels of the study area. These data allowed an approximation of pollutant loadings due to dredging and disposal activities. Performance of these subtasks provided necessary information to assess the impacts of dredging and disposal in the study area.

Summary of Dredging Activity in the H-GAC 208 Area

The volumes of materials dredged from the H-GAC area channels by the U.S. Army Corps of Engineers have been calculated on a tow-mile reach basis. Approximately 2.7 million cubic yards are dredged annually from the study area. Of this total, over 2.5 million cubic yards are dredged from the Houston Ship Channel. Thus, 93% of the federal dredging in the area is performed in the Houston Ship Channel. Cedar Bayou, Clear Creek, and Clear Lake Channels account for the remainder. In most reaches of the Houston Ship Channel the frequency of dredging is once in every two to three years. In Cedar Bayou and Clear Lake dredging occurs less frequently. Cedar Bayou is dredged every two to four years, while the lower end of the Clear Creek Channel is dredged once in four years. The upper end of the Clear Creek Channel is dredged about once every twenty years.

TABLE IV-9

SAMPLE OF EROSION PRINTOUT

```
    LANCASTER PENNSYLVANIA STEVENS AVE DISTRICT **** RELEASE II****
    STORM OF SEPTEMBER 14,1973  DURATION 9 HOURS
  SUMMARY OF QUANTITY AND QUALITY RESULTS AT LOCATION 31
  FLOW IN CFS AND QUALITY IN (MG/L)

TIME    FLOW    BOD    SUS-S*    COLIF    COD    SET-S    NIT    PO4    GREASE    SUS-S WITHOUT EROSION
```

*Suspended solids with construction related erosion

All disposal along the Houston Ship Channel is accomplished in confined land disposal sites, In Cedar Bayou some open water sites are used, while only open water sites are used in Clear Creek and Clear Lake,

The sediment of the Houston Ship Channel are heavily contaminated with industrial and municipal pollutants. More sediment chemistry data is needed in the smaller channels to assess their pollution potential upon resuspension. Where data are available, the pollutant loadings resulting from dredging and disposal in Cedar Bayou generally exceed those for the other channels in the study area. This phenomenon is primarily a result of the difference in disposal practices used. The use of open water sites to dispose of relative large volumes of material dredged from Cedar Bayou results in high pollutant loadings when compared to the pollutant loads discharged from the Hosuton Ship Channels confined sites. The confined sites greatly reduce the Solids and other pollutant loadings entering the receiving waters.

More data is needed throughout the study area to physically characterize the channel sediments. Generally, the sediments are fine textured and thus tend to remain in suspension for longer periods than course-grained materials. The physical and chemical effects of disposal on the marshes and nursery areas identified in the study area should be assess prior to future disposal.

Methodology

Pollution loads due to dredging activities and the resultant impacts of these loads can be assessed through the quantification of various associated factors. To estimate the pollutant loading, the necessary parameters include: I) present and projected volumes of material dredged and disposed of annually, 2) frequency of dredging, 3) the types of dredging and disposal practices used, 4) the contaminant content of the dredged material, and 5) the quantities of pollutants introduced to the water column. To assess the impact of the pollutant loads on area ecosystems it is necessary to identify: 1) the area affected by the discharge, 2) the pollutant concentrations and donations in the affected area, 3) the sensitive environment in the affected area, and 4) the effects of pollutant concentrations and duration on the sensitive environments of the affected area.

To obtain the present and projected annual volumes of dredged materials the frequencies of dredging materials, the frequencies of dredging and the types of dredging and disposal practices, historical records were requrested and received from the Corps of Engineers, Galveston District.

An analysis of the volume of material dredged from the study area has been performed. The initial stage of this analysis was a preparation of computer programs for processing historical dredging data. All available records of new work and maintenance dredging by pipeline dredge in the study area have been obtained from the U.S. Army Corps of Engineers. These records are listed by dredging contract and year, and detail the cubic yards removed between specific stations along the channels.

The goal of this data analysis procedure was to determine a distribution of total material removed from the channels, and shoaling rates and dredging frequencies for every two-mile segment of the channels. Further, the material was then sorted into the nearest available spoil disposal area to yield a total and yearly average accumulation in that area. This data base then provided the basis for projected future volume and area requirements.

The initial data available to the programs is punched on cards exactly as it is listed on the dredging records of the Corps. These records employed Corps station numbers for reference. These were converted by the program to standard channel mile numbers. This conversion can be made by applying the following equation:

$$m = m_o + f/5280$$

where:

m = channel mile number

f = station number (feet)

m_o = a constant (miles)

The constant, m_o, is always the distance in miles from station 0+00 to the zero mile location. For the Houston Ship Channel, mile zero is at Bolivar Road and station 0+00 is at Morgans Point. The station number indicates a distance in feet as though the plus sign were disregarded. To determine an equivalent channel mile number from any given station number it is first necessary to know in which reach of the channel the station is located.

The following table lists the appropriate values of m_o for the navigable channels in the study area.

Channel and Reach	f(from)	f(to)	m_o
Houston Chip Channel			
Morgans Pt. to Houston T.B.	0+00	505+49	26.21
	512+00	812+24	26.09
	956+36	1174+72	25.88
	1176+85	1281+40	25.84
Houston Turning Basin	0+00A	13+50A	50.67
Buffalo Bayou	0+00	215+00	50.93
Five-Mile Cut Channel	2+00	100+00	0.00
Barbour Terminal	-10+00	28+50	0.00
Greens Bayou	0+00	87+25	0.00
Cedar Bayou	-1+50	301+56	-2.70
Clear Creek & Clear Lake	25+00	470+00	-2.01

The volumes dredged in each contract are divided proportionately into the standard two-mile segments. An intermediate printout is available at this point listing the following information for each contract:

1) Year, channel mile at station zero, number of dredged reaches in the contract, an adjustment factor from estimated to actual volumes as specified by the Corps, and the fraction of dredged volume which was new work.

2) A list of reaches dredged specifying end points by station and mile numbers, total volumes from the dredging records, and an average volume per mile.

3) A list of two-mile segments, each beginning at an even mile number, from which material was taken under the contract; the volume dredged from each segment; and the actual distance dredged in each two-mile segment. This printout proved useful for double checking the input parameters and data before proceeding with the main sorting procedure.

Information from the preceeding phase of the analysis was sorted into a file which contained a "pigeon hole" for each standard two-mile segment. After processing of all the past contracts for the channel under consideration, each "pigeon hole" contained year designations for each contract that was dredged in that particular two-mile segment. With each year was stored the dredged volume of maintenance spoil, new work spoil, elapsed years since the previous maintenance dredging, and the actual range in miles that was dredged in that segment. A dredging frequency was calculated for maintenance work by averaging the elpased years between maintenance dredgings. A logical check was made on the ranges to account for cases where the work in one segment was divided between two contracts. The volumes were then summed to yield totals for maintenance dredging in each two-mile segment. The average maintenance volume since the first new work contract by the total elapsed years in interpreted as the shoaling rate for the two-mile segment.

For channels which are already maintained to the dimensions fully authorized by Congress, the future dredging requirements will be equal to these present shoaling rates. To arrive at a more accurate representation of future requirements for channels which are not year up to authorized dimensions, the effects of new work to be done was considered. The increased volumes of these channels, from present size, yielded the volume requirements for new work disposal.

The preceeding methodology provided the necessary data base for a projection of the future volume requirements of dredged material. The results are presented in detail below in units of ac-ft for 10-year and 25-year projection periods. The assumption has necessarily been made that the authorized dimensions will be attained within the first 10 years of the projection periods. Results in units of cubic yards are also provided for the present and projected annual shoaling rates and the anticipated new work volumes. A useful conversion factor is that 1 ac-ft is equal to 1613.3 cu. yd.

The procedure was followed by a routine to sort the dredged material into the nearest available spoil disposal area. This routine approximated yearly average accumulation in each area. This resulting data base provided the basis for projecting future disposal area capabilities.

A computer program was prepared to operate on the data files containing the dredging records by two-mile reach for each channel. The input data to this program defined each disposal area along the channel by identificaiton number, beginning and ending station numbers, and acreage. An intermediate listing provided the following quantities for each site:

1) The actual reach in miles was determined by the above conversions from station numbers.

2) An effective reach was determined by dividing the channel reaches between disposal areas equally and assigning the material dredged from these reaches to the nearest disposal

area. This process assumes that dredged material is always transported to the nearest available disposal area.

3) The yearly maintenance volumes placed in each disposal area were determined by proportionately assigning the shoaling rates per two-mile reach to the nearest disposal area.

4) A maintenance deposition rate (R) in feet per year was determined from the formula

$$R = \frac{(V)\ (27)}{(A)\ (43560)},$$

where V is the yearly maintenance in cubic yards, A is the area in acres, and the constants are conversions from feet to yards and acres. The assumption is made that all spoil is confined within the limits of the disposal area and distributed evenly over that area.

5) Finally, the acreages for each disposal area were listed.

The yearly maintenance volumes and deposition rates found by the above process can be considered as accurate projections of future capabilities of disposal areas along the channel which are already maintained at authorized dimension. For the projects which have new work remaining, the volumes of virgin material to be disposed of were sorted into the appropriate effective reaches of the disposal areas. Thus, for each disposal area, a total projected annual deposition rate, as well as the depths of virgin material to be expected from new work, has been determined.

To evaluate the effects of contaminated material disposal on area ecosystems, the nature of the contaminants must first be known. Once the contaminants are identified, attention can then be focused on the factors which influence the behavior of each contaminant during dredging and disposal operations.

To chemically characterize the sediments of the ports and waterways of the study area, pertinent literature and data bases were collected and analyzed. These data sources included raw data from state and federal agencies and many publicaitons dealing with the Texas Coastal environment. The data analysis was performed by first segmenting the major waterways into two-mile reaches. The literature and other data sources were then searched to locate sediment analysis information for each of the reaches. The basis for determining the contamination of sediments were the E.P.A. screening levels shown in Table IV-10. If the concentration of a parameter in a sediment sample exceeded the screening level, the two-mile

TABLE IV-10

PROPOSED EPA GUIDELINES FOR DETERMINING THE UNACCEPTABILITY OF DREDGED SEDIMENTS FOR OPEN WATER DISPOSAL

1974

This list applies only to EPA Region VI.

Parameter	Screening Level (mg/kg)
Volatile Solids (V.S.)	80,000
Chemical Oxygen Demand (COD)	50,000
Total Kieldahl Nitrogen (TKN)	1,000
Biochemical Oxygen Demand (BOD)	38,000
Phosphate (PO_4)	900
Oil and Grease (O&G)	1,500
Arsenic (As)	5
Cadmium (Cd)	2
Chromium (Cr), Total	100
Copper (Cu)	50
Lead (Pb)	50
Mercury (Hg)	1
Nickel (Ni)	50
Zinc (Zn)	75
Manganese (Mn)	512
Iron (Fe)	20,000
Total Organic Carbon (TOC)	*
Total Organic Nitrogen (TON)	*
Silver (Ag)	*
Tin (Sn)	*
Organochloride insecticides	*
Pholychlorinated biphenols	*
Immediate Oxygen Demand (IOD)	**

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* Indicates these parameters require further study before screening levels can be established.

** The dissolved oxygen level in the receiving water should not be depressed below Water Qualtiy Standards limits by 5% sediment during a 15-minute period.

reach from which the sample was taken was considered to be contaminated by that parameter.

Once the quantities of materials to be dredged and the levels and nature of the contaminants were known, it was possible to estimate the quantities of pollutants introduced into the water column during disposal. The pollutant load will depend on the type of disposal practiced. In the study area, land disposal into a confined site is used in most instances. The effluent from confined sites will usually be decanted back into the dredged channel after a period of retention. For the purposes of this study it was assumed that the volume of an effluent from a confined site was four times the volume of material dredged. Further, it was assumed that the total suspended solids (TSS) concentration in an effluent from a confined site was an average minimum of 8 g/l. These assumptions were based on the results of conversations with Corps of Engineers (Galveston District) and E.P.A. (Dallas, Region VI) personnel. The use of the ratio of 4:1 and the concentration of 8 g/l yields conservation, yet reasonable estimates of effluent volumes and TSS levels associated with confined sites.

Thus, given the annual volumes of materials dredged and disposed of into the confined disposal sites of a channel (Vc), an estimate of the volume of effluent (Qc) from the confined sites is Qc = 4 Vc. The annual solids loading (Sc) from the confined sites of the channel is estimated by Sc = 8 Qc, where Qc is in liters. to estimate the annual BOD_5, COD, PO_4, Kjeldahl Nitrogen and heavy metals loadings from the confined sites of a channel, the average sediment concentrations of the parameters in each channel were used. This average concentration (p_i) of a parameter is a channel was multiplied by Sc to yield the estimated annual loading (Lp_ic) of the parameter from the confined sites used for disposal along the channel.

To estimate the annual channel loadings from disposal into open water unconfined sites, the annual volumes (Vu) of materials dredged and disposed of into such sites were used. Based on unpublished soils analysis data from the Corps' Soils Laboratory in Galveston, a reasonable approximation of the density of sediments in the study area is 100 lb/ft^3. Thus, using appropriate unit conversions, the annual loading of a parameter due to open water disposal of material dredged from a channel is $100\ Vu \cdot p_i = Lp_iu$. The total annual loading Lp_i is a pollutant due to dredging and disposal is therefore $Lp_ic = Lp_ku - Lp_i$. Projected increases in maintenance dredging volumes were used to project future loadings. No significant increases were used to project future loadings. No significant increases are projected for the study area. So the 5, 10, and 20-year loadings are essentially the same as present.

The above technique was selected for estimating loadings because direct measurements were not available. The desirable means to approximate loadings is to monitor the actual discharges from confined sites and from pipelines which discharge into open water. Another means of estimating loadings is by use of standard elutriate tests on the sediments to be dredged. The U.S.A.C.E. (1976) describes this test procedure. To estimate loadings with elutriate data, unfiltered and filtered elutriates should be analyzed and compared to water quality at the dredge and receiving water sites. No readily available elutriate test data could be located that were pertinent to the study area.

To evaluate the impact of dredge disposal loadings, guidelines and interim guidance have been developed by the E.P.A. (1975) and the U.S.A.C.E. (1976), respectively critical habitats in the study area have been identified by the Texas Parks and Wildlife Department. These sensitive environments should be evaluated against the pollutant loadings with the procedures described by the E.P.A. (1975) and the U.S.A.C.E. (1976).

Results

The Houston Ship Channel is federally maintained by contract pipeline dredge. The projects include a 51-mile long deep draft channel from Bolivar Roads across Galveston Bay, along the San Jacinto River and Buffalo Bayou to the Houston Turning Basin. The waterway also includes a light-draft channel in Buffalo Bayou for four miles above the main turning basin, as well as tributary channels at Five Mile Cut, Barbour Terminal, Greens Bayou and Cedar Bayou. Over 67 miles of channel are maintained by the federal projects. Of this, all but the 26 miles south of Morgans Point are in the study area.

Table IV-11 indicates that the total shoaling rate in the above channels in the study area is about 2,500,000 cubic yards, or 1550 acre-feet, per year. The acreage shoaling rate along the deep draft main channel is about 175,000 cubic yards per year per two-mile reach. Shoaling in the tributaries is somewhat less at about 34,000 cubic yards per year per two-mile reach. The area of heaviest shoaling appears to be from Morgan's Point to Peggy Lake (Miles 26-32) where the shoaling is as much as 300,000 cubic yards per year per two-mile reach and the dredging frequency is as low as 2.2 years. Most of the channels require every 2.5 to 4 years.

As the existing project is nearly 100% complete, excluding inactive portions, little new work is anticipated, and the present shoaling rates are the only basis for future requirements. The ten-year and 25-year projections for dredged material volumes for the project in the study area 16,000 and 40,000 acre-feet, respectively.

The portion of the Houston Ship Channel in the study area utilizes 28 disposal areas including five which are used exclusively for dredging in Cedar Bayou (Table IV-12). A total of 6370 acres are available for the disposal of dredged materials from the two projects. Cedar Bayou Disposal Areas Nos. two-four, totaling 175 acres, are in open water reaches of Galveston Bay. The remainder of the areas are reported to be completely leveed.

Other Disposal Areas used exclusively for dredging in tributary channels are No. 22A on the Greens Bayou Channel. Disposal areas located at the intersection of two channels and receiving material from both are: No. 17, the same area as Cedar Bayou Area No. 1; No. 18, which receives all the material dredged from Barbour Terminal; and Nos. 22 and 23, which receive material from Mile 0.0 to Mile 0.76 in Greens Bayou. Disposal Areas 31-38 are along Buffalo Bayou above the Houston Ship Channel Turning Basin.

The only authorized new work not yet completed is in the vicinity of the Houston Ship Channel Turning Basin and is not expected to appreciably alter the accommodation capability of the effected disposal areas.

It should be noted that the disposal area numbers used herein were taken from the Final Environmental Statement for maintenance dredging of the Houston Ship Channel. These numbers are not always consistent with the designations used previously in the Public Notices.

The project in the study area provides for a channel seven feet deep by 60 feet wide, from the mouth of Clear Creek, through Clear Creek and Clear Lake, to League City. Also, included is an old entrance channel between Seabrook Island and the west shoreline of Galveston Bay. The total channel length in the study area is about eight miles.

Shoaling is very light in these channels, totaling only about 14,000 cubic yards per year. The most frequent dredging is about every four years. The dredging requirements projected for ten-year and 25-year periods are 86 acre-feet and 215 acre-feet, respectively (Table IV-11).

The portion of this project in the study area utilizes four areas for the disposal of hydraulically dredged material (Table IV-12). A total of 83 acres are in use; all of these are in open water.

Maintenance dredging records indicate that no such dredging has occurred in either the Bayport Channel or Dickinson Bayou. When or if such maintenance is required, the methodology presented above can be used to estimate future dredging volumes.

TABEL IV-11

PRESENT AND PROJECTED VOLUMES OF MATERIAL DREDGED FROM H-GAC STUDY AREA

CHANNEL MILE		DREDGING FREQUENCY	MAINTENANCE DREDGING			CHEMICAL POLLUTANTS PRESENT	AUTHORIZED NEW WORK	10 YEAR FORECAST	25 YEAR FORECAST
FROM	TO	(YRS)	HISTORICAL AVERAGE (CY/YR)	PROJECTED INCREASE (CY/YR)	TOTAL PROJECTED (CY/CR)		(CY)	(AC-FT)	(AC-FT)
Houston Ship Channel									
26.0	28.0	2.2	335935	0	335935	YES	0	2082.2	5205.6
28.0	30.0	2.2	316696	0	316696	YES	0	1963.0	4907.5
30.0	32.0	2.4	284931	0	284931	YES	0	1766.1	4415.3
32.0	34.0	2.9	146563	0	146563	YES	0	908.5	2271.1
34.0	36.0	2.6	161386	0	161386	YES	0	1000.3	2500.8
36.0	38.0	2.8	142536	0	142536	YES	0	883.5	2208.7
38.0	40.0	4.3	95960	0	95960	YES	0	594.8	1487.0
40.0	42.0	2.3	107949	0	107949	YES	0	669.1	1672.8
47.0	44.0	2.6	143722	0	143722	YES	0	890.9	2227.1
42.0	46.0	2.9	140526	0	140526	YES	0	871.0	2177.6
46.0	48.0	2.3	144245	0	144245	YES	59333	930.9	2272.0
48.0	50.0	2.3	100868	0	100868	YES	296667	809.1	1746.9
50.0	52.0	2.6	161394	0	161394	YES	0	1000.4	2501.0
52.0	54.0	2.6	28774	0	28774		0	178.4	445.9
54.0	56.0	4.5	16893	0	16893		0	104.7	261.8
Barbour Terminal									
-.2	0.0	3.0	7778	0	7778		0	48.2	120.5
0.0	.5	3.5	20966	0	20966		0	130.0	324.9
Greens Bayou									
0.0	1.6	4.0	26004	0	26004		0	161.2	403.0
Cedar Bayou									
-2.7	-2.0	3.8	17942	0	17942	YES	0	111.2	278.0
-2.0	0.0	2.3	98871	0	98871	YES	0	612.8	1532.1
0.0	2.0	3.8	42939	0	42939	YES	0	266.2	665.4
SUBTOTAL			2,542,878		2,542,878			15982.3	39624.6

TABLE IV-11 (contd.)

PRESENT AND PROJECTED VOLUMES OF MATERIAL DREDGED FROM H-GAC STUDY AREA

CHANNEL MILE FROM	CHANNEL MILE TO	DREDGING FREQUENCY (YRS)	MAINTENANCE DREDGING HISTORICAL AVERAGE (CY/YR)	MAINTENANCE DREDGING PROJECTED INCREASE (CY/YR)	MAINTENANCE DREDGING TOTAL PROJECTED (CY/CR)	CHEMICAL POLLUTANTS PRESENT	AUTHORIZED NEW WORK (CY)	10 YEAR FORCAST A_E (AC-FT)	25 YEAR FORCAST A_E (AC-FT)
Clear Creek and Clear Lake									
0.0	2.0	4.0	47	0	47		0	.3	.7
2.0	4.0	21.0	307	0	307		0	1.9	4.8
4.0	6.0	21.0	760	0	760		0	4.7	11.8
North Fork									
0.0	.7	3.8	12764	0	12764		0	79.1	197.8
SUBTOTAL			13878		13878			86.0	215.1

TABLE IV-12

DISPOSAL SITE DESCRIPTIONS FOR THE H-GAC AREA

DISPOSAL AREA NUMBER	LEVEE STATUS	CHEMICAL POLLUTANTS PRESENT	EFFECTIVE REACH		AREA	MAINTENANCE MATERIAL				AUTHORIZED NEW WORK DEPOSITS
			FROM (CHANNEL MILES)	TO	(ACRES)	HISTORICAL AVERAGE VOLUME (CY/YR)	HISTORICAL AVERAGE DEPTH (FT/YR)	PROJECTED ADDITIONAL DEPOSITS (FT/YR)	TOTAL PROJECTED DEPOSITS (FT/YR)	(FT)
Houston Ship Channel										
17(1)	L	YES	25.99	26.81	250	156978	.39		.39	
18(2)	L	YES	26.81	29.13	950	407604	.27		.27	
19	L	YES	29.13	32.26	660	442359	.41		.41	
20	L	YES	32.26	34.16	250	140705	.35		.35	
21	L	YES	34.16	38.27	730	303658	.26		.26	
22(3)	L	YES	38.27	40.01	80	86437	.68		.68	
22A(4)	L		.76	1.65	175	16154	.06		.06	
23(3)	L	YES	40.01	41.80	50	101512	1.26		1.26	
24	L	YES	41.80	44.26	335	172875	.32		.32	
25	L	YES	45.39	46.33	500	67159	.08		.08	
26	L	YES	44.26	45.39	500	79142	.10		.10	
27	L	YES	46.33	47.09	580	54638	.06		.06	
28	L	YES	47.09	48.89	386	110434	.18	0.00	.18	.52
29	L	YES	48.89	50.14	219	67321	.19	0.00	.19	.09
30	L	YES	50.14	50.82	123	54746	.28		.28	
31(5)	L	YES	50.82	51.40	210	47104	.14		.14	
32	L	YES	51.40	51.65	10	20251	1.26		1.26	
33	L		51.65	52.09	30	29114	.60		.60	
34	L		52.09	52.30	5	3134	.39		.39	
35	L		52.30	52.83	10	7630	.47		.47	
36	L		52.83	53.24	25	5858	.14		.14	
37	L		53.24	53.90	9	9469	.65		.65	
38	L		53.90	56.00	5	18350	2.28		2.28	
SUBTOTAL					6.092	2,404,632				

TABLE IV-12 (contd.)

DISPOSAL SITE DESCRIPTIONS FOR THE H-GAC AREA

DISPOSAL AREA NUMBER	LEVEE STATUS	CHEMICAL POLLUTANTS PRESENT	EFFECTIVE REACH		AREA	MAINTENANCE MATERIAL				AUTHORIZED NEW WORK DEPOSITS
			FROM	TO		HISTORICAL AVERAGE		PROJECTED ADDITIONAL DEPOSITS	TOTAL PROJECTED DEPOSITS	
			(CHANNEL MILES)		(ACRES)	VOLUME (CY/YR)	DEPTH (FT/YR)	(FT/YR)	(FT/YR)	(FT)
Cedar Bayou Channel										
1(6)	L		-3.73	-1.96						
2	W	YES	-1.96	-1.38	58	28557	.30			.30
3	W	YES	-1.38	- .43	55	47282	.53			.53
4	W	YES	-.43	.66	62	35330	.35			.35
5	L	YES	.66	2.85	46	28732	.39			.39
6	L		2.85	3.00	57	0	0.00			0.00
SUBTOTAL					278	139901				
Clear Creek and Clear Lake										
3	W		.69	1.92	14	29	.00			.00
4	W		1.92	2.58	33	90	.00			.00
5	W		2.58	3.12	17	83	.00			.00
6	W		3.12	6.76	19	896	.03			.03
SUBTOTAL					83	1098				

Footnotes:
(1) Same as Cedar Bayou area 1, material included in this entry.
(2) Includes material from Barbour Terminal
(3) Includes material from Greens Bayou Channel.
(4) Greens Bayou Channel only.
(5) Areas 31 through 38 are along Buffalo Bayou.
(6) Same as HSC area 17, see above.

Non-Federal Dredging

In addition to the material dredged by federal contract the Port of Houston reports an additional 1,200,000 cu. yds. per year of dredged material deposited in the disposal area by private interests.

These non-federal requirements along the Houston Ship Channel are sufficient to place an additional 1.6 ft of material in all available disposal areas within ten years. It is expected, however, that the distribution of these materials along the channel may be uneven, thus imposing much larger accumulations on specific disposal areas. If much of the expected volumes originate in the upper reaches of the channel, lack of accommodation capability may be expected in the near future.

The ten-year disposal requirements for non-federal material in the Clear Creek-Clear Lake project is sufficient to deposit areas.

To determine the true magnitude of dredging requirement by non-federal interests, it is recommended that:

1) A study be made of the files of the Permit Section of Galveston District, U.S.A.C.E., detailing the history of virgin and maintenance dredging activities by the public port facilities, the petrochemical industry, and other private interests. Data should be compiled on the quantities of dredged material, the frequency and location of dredging, and the location of the disposal sites used.

2) Inquiries be made of at least the principal permit holders, if not all of them, to determine anticipated future dredging needs. Again, particular attention should be given to the quantities of material, and the specific locations of dredging and disposal sites.

Table IV-13 chemically characterizes the sediments in the major dredged channels of the study area. The Houston Ship Channel sediments are polluted with all types of contaminants. It appears that the number of pollutants increases with an increase in sediment chemistry data. The sediments of the other channels have not been well studied. The sediments of Clear Creek and Clear Lake Channels are likely contaminated with nutrients form the several sewage treatment plants discharging into the creek and lake. More sediment data is needed to assess the pollution potential of dredged sediments in Cedar Bayou and Clear Lake.

Table IV-14 presents the average sediment concentrations of pollutants in the H-GAC area channels. For the smaller channels no data was available for many of the parameters. Table IV-15 gives the estimated pollutant loadings due to dredging and disposal in

TABLE IV-13

CHEMICAL CHARACTERIZATION OF DREDGED MATERIALS - H-GAC AREA

CHANNEL	MILE	PARAMETERS EXCEEDING EPA SCREENING LEVELS	REFERENCES
Houston Ship Channel	26-28	Cd, Zn, As, Mn, Pb, TKN, PO_4, COD, O&G, Aldrin**, DDE**, DDT**, 2-4-5-T**, 2-4-D	1, 2, 4, 5, 8
	28-30	An, As, Mn, Pb, TKN, COD, O&G	1, 2, 5, 8
	30-32	Zn, As, Mn, TKN, V.S., O&G	1, 2, 5, 8
	32-34	Zn, Mn, Ni	1, 4
	34-36	An, As, Mn, Pb, V.S., COD	1, 2 5, 8
	36-38	Cd, Zn, As, Pb, Mn, Ni, Cr, Hg, TKN, PO_4, O&G, Lindane**, Aldrin **, DDE**, DDT**	1, 4
	38-40	Cd, Zn, Mn, Pb, Ni, Cr, Hg	1,2
	40-42	Cd, Zn, Pb, Cu, Cr, PO4, V.S., Lindane**, DDD**	1, 2, 4
	42-44	Cd, Zn, Pb, Cu, Cr, V.S. COD, O&G	1,2
	44-46	Cd, Zn, As, Pb, Ni, Cu, Cr, BOD, COD, O&G	1,2
	46-48	Cd, Zn, As, Pb, Cu, Cr, Hg, PO_4, BOD, COD, O&G	1, 2, 4
	48-50	Cd, Zn, Pb, Cu, Cr, V.S., BOD, COD	1, 2
	50-51.59	Cd, Zn, As, Pb, Cu, Cr, TKN, PO_4, V.S. COD, O&G, Lindane**, Aldin**, Dieldrin**, DDE**, DDD**	1, 2, 3, 4
Clear Creek and Clear Lake	0-0.53	TKN, α-HBC**	1, 6
	0.53-2.53	No Data	
	2.53-4.53	No Data	
	4.53-6.53	No Data	
	6.53-6.76	No Data	

TABLE IV-13 (contd.)

CHEMICAL CHARACTERIZATION OF DREDGED MATERIALS - H-GAC AREA

CHANNEL	MILE	PARAMETERS EXCEEDING EPA SCREENING LEVELS	REFERENCES
Clear Creek and Clear Lake, North Fork	1.08-1.76	None	6
Cedar Bayou	-3.73-1.73	Zn, TKN	
	-1.73-0.73	Zn, Pb, TKN	7
	0.7-2.73	No Data	7
	2.73-3.01	No Data	

each dredged channel. No estimates were made where data were not available. It should be stressed here that the values for such parameters will likely be greater than zero, since natural sediments have measureable levels of most of the parameters. Also, the loadings for Clear Creek and Cedar Bayou include disposal into open water sites. The Houston Ship Channel has only confined sites. Therefore, the loadings due to dredging and disposed in the smaller channels appear disproportionately large when compared to the Houston Ship Channel.

Pertinent literature sources were searched in an effort to physically characterize the sediments of channels in the study area. Insufficient data was available to perform such a characterization. However, conversations with Corps of Engineers, Galveston District, personnel indicates that the sediments in the Houston Ship Channel are of very fine texture. Such sediments are likely to remain suspended for much longer periods than coarser materials. Thus, when these materials enter the water column they may be carried long distances by currents.

The majority of dredging in Texas is presently undertaken by governmental agencies to support navigational interests in both waterways and harbors. Lesser activities occur within the private sector and include the dredging and maintenance of channels, turning basins, marinas, and other coastal facilities and sand and gravel mining. The material dredged can be described as either maintenance material or virgin material. Virgin material is generally comprised of emergent of submergent soil which has not previously been dredged. Maintenance material consists of silt, sand, clay or other particles which are deposited from an overlying water column into an existing dredged waterway or harbor. These depositions, or sediments, vary widely in chemical composition and studies have shown that certain of these sediments contain and release chemical contaminants when they are resuspended.

The release of chemical contaminants from resuspended sediments can have various adverse effects on receiving waters and the organism which inhabit them. The release of heavy metals, pesticides and and other substances can increase the ambient concentrations of these materials to toxic or sublethal harmful levels. Nutrient releases, primarily the release of nitrogen and phosphorus forms can lead to increased photosynthetic activity and upset the oxygen balance of the receiving waters. The release of oxygen demanding materials can reduce the dissolved oxygen content of the waters, thus causing organism avoidance of the area or in extreme cases, organism mortality. All of these factors, and others, associated with the disposal of dredged materials constitute a potential threat to the stability of some coastal ecosystems.

TABLE IV-13 (contd.)

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TABLE IV-14

AVERAGE SEDIMENT CONCENTRATION OF POLLUTANTS IN H-GAC AREA CHANNELS (MG/KG)

	H.S.C.			CEDAR BAYOU			CLEAR CREEK		
	LOW	HIGH	AV.	LOW	HIGH	AV.	LOW	HIGH	AV.
COD	2400	42500	32191.71	15000	49600	24988	5900	41200	20756
TKN	120	1830	1003.94	140	1600	782	150	1890	684
BOD	28000	28000	28000.00						
PO_4	62.25	3244.80	1793.35						
O&G	80	5630	2954.56	270	1360	794	30	280	107.8
As	4.72	13.05	8.09						
Cd	.70	2.20	1.67						
Cr	19.60	122	57.56						
Cu	13.10	100	53.06						
Pb	4	165	94.38	1	52	9.36	4	13	7.56
Hg	.10	.90	.47	.10	.86	.22	.10	.10	.10
Ni	19.60	32.20	26.20						
Zn	5	75	57.82	36	90	56.27	6	61	34.11
Mn	120	1091.50	482.25						
Fe	4.3	9870	4937.15						
TOC	4.3	4.3	4.3						
Ag	2.1	2.1	2.10						

TABLE IV-15

SUMMARY OF POLLUTANT LOADINGS DUE TO DREDGE SPOIL DISPOSAL IN THE H-GAC AREA CHANNELS

	HSC (RM 26.0)	CEDAR BAYOU (RM -2.7)	CLEAR CREEK (RM 0.0)
Total Dredged Material (cu. yd./day)	6,600	380	3
Effluent Total Suspended Solids (lb/day)	118,000	1,100,000*	11,000*
Loadings (lb/day)			
COD	3,300	23,700	190
TKN	100	740	6
BOD	2,870		
PO_4	180	750	10
O&G	300		
As	0.8		
Cd	0.2		
Cr	5.9		
Cu	5.4		
Pb	9.6	8.8	0.07
Hg	0.04	0.2	0.001
Ni	2.7		
Zn	5.9	50	0.3
Mn	50		
Fe	510		
TOC	4.4		
Ag	0.2		

* These quantities include dredged material discharged into open water disposal sites. Thus, the quantities appear disproportionately greater than areas where only confined sites are used.

Note: Although dredging activities are intermittent with regard to time and spatial distribution, the impacts continue over time and are usually normalized to annual loadings to reflect the continuous nature of the impact.

Physical effects of dredged material are generally more obvious than chemical effects. Physical effects include increased turbidity, inhabiting photosynthesis, and the covering of habitat. The transport by currents of materials after placement is a major problem associated with the aquatic discharge of dredged materials.

The impact of the pollutant loading due to dredging and disposal in the study area will depend on a number factors. To evaluate such impact it is necessary to predict: 1) the area likely to be affected by the discharge, 2) the pollutant concentrations and durations in the affected area, 3) the sensitive environments in the affected area, and 4) the effects of pollutant concentrations and durations on the sensitive environments in the affected area.

The Houston Ship Channel disposal areas are all confined sites. The sensitive areas likely to be affected by discharges from these sites are shown in Table IV-16. As this table indicates the most serious conflict along the channel is due to urban concentration and the resulting competitiveness for shoreline space. The sensitive environments are between miles 26-36, the lower and of the land-locked portion of the channel, five-mile cut, Barbour Terminal, and Greens Bayou. These habitats consist of grass flats and marshes, which normally would be used as nursery areas for estuaries and marine organisms. The potential detrimental effects to these environments may include physical and chemical degradation. Since the disposal sites for the Ship Channel are all confined, the physical impacts of disposal can be minimized if: 1) disposal sites are not designated in the marshes or grass flats, 2) disposal sites are located such that drainage to the marshes and grass flats is not disturbed, and 3) discharges from the disposal sites are directed back into the channel, avoiding marsh and grass flat areas.

To minimize the impact of chemical pollution due to disposal, some predictive tools may be used. The E.P.A. (1975) and U.S.A.C.E. (1976) provide that pollutant releases may be evaluated by the elutriate test. This test involves the mixing of sediment to be dredged with overlying water at a ratio of 1:4 by volume. After a settling period of 30 minutes, the supernatant simulates the effluent from a confined site. Water chemistry is then performed to determine the increase in concentration of dissolved and suspended pollutants over ambient. The chemistry data should be evaluated with respect to the environments in the area affected by the discharge. The duration of the discharge and dilution that may occur should be considered in this evaluation.

The use of marsh and grass flat areas for disposal would minimize environmental risks. If these areas cannot be avoided, environmental risks could be minimized if the impacts of toxic materials, nutrients, and oxygen demanding materials on the marsh and grass flat ecosystems

TABLE IV-16

CRITICAL OR SENSITIVE ENVIRONMENTS IN THE H-GAC STUDY AREA

GALVESTON BAY CHANNELS

Location	A	B	C	D	E	F	G	H	References
26 - 28							X	X	2, 4
28 - 30							X	X	2, 3, 4, 5
30 - 32		X					X	X	2, 3, 4, 5
32 - 34		X					X	X	2, 3, 4, 5
34 - 36		X					X	X	2, 3, 4, 5
36 - 38		X							5
38 - 40		X							5
40 - 42		X							5
42 - 44		X							5
44 - 46		X							5
46 - 48		X							5
48 - 50		X							5
50 - 52		X							5
Light Draft Channel									
52 - 54		X							5
54 - 56		X							5
Five-Mile Cut Channel									
0 - 1.86		X				X	X		2, 3, 4, 5
Barbour Terminal Channel									
-.19 - .54		X				X			2, 3, 4, 5
Greens Bayou Channel									
-.76 - 1.65		X				X	X		2, 3, 4, 5

TABLE IV-16 (contd.)

CRITICAL OR SENSITIVE ENVIRONMENTS IN THE H-GAC STUDY AREA

GALVESTON BAY CHANNELS

Location	A	B	C	D	E	F	G	H	References
Clear Creek Clear Lake									
-1.53 - 2		X					X		2, 3, 4, 5
2 - 4		X					X		2, 3, 4, 5
4 - 6.76		X					X		2, 3, 4, 5
Cedar Bayou									
-3.73 - 2	X		X	X	X			X	1
2 - 4	X		X	X	X			X	1

A - Areas of high natural productivity or essential habitat for living resources, including fish, wildlife, and the various trophic levels in the food web critical to their well-being.

B - Areas of urban concentration where shoreline utilization and water uses are highly competitive

C - Shrimp nursery

D - Finfish nursery

E - Bluecrab nursery

F - Grass flats

G - Marshes

H - Freshwater input

TABLE IV-16 (contd.)

LITERATURE SOURCES

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were evaluated prior to disposal. To predict the effects of toxic materials, the elutriate test results should be compared with toxicity data reported in the literature. (28) If the elutriate levels appear high, bioassays may be performed on elutriates. The U.S.A.C.E. (1976) provides a procedure for performing these tests. Nutrient impact can be evaluated by use of algal growth studies, (29)

Nutrient and oxygen demand loadings should be carefully considered prior to site selection along the ship channel, as well as other channels in the study area.

The process of algal respiration resulting in oxygen depletion, was cited as the probable cause of 48 fish kills in the Houston - Galveston area during the warmer months of 1971 and 1972 (Knudson and Belaire, 1975). Though none of these fish kills were attributed directly to dredging activities, excessive increases in nutrient levels during warmer months can aggravate eutrophication problems that exist in some of the shallow estuaries of Texas. Frequent fish kills have been reported throughout channels in the study area. Most of these kills have occurred during warmer months as a result of oxygen depletion.

In Cedar Bayou both confined and open water sites are used, while only open water sites are used in Clear Lake. The sensitive environments in these channels are marshes in Clear Lake and a variety of valuable estuarine habitats along Cedar Bayou. The lack of sediment chemistry data for these channels makes it difficult to suggest ecological evaluations that might minimize environmental risks due to contaminated material disposal.

However, the several municipal discharges into Clear Creek and Clear Lake increase the likelihood of nutrient contaminated sediments. According to Texas Water Quality Board records, many eutrophication related fish kills have occurred in this area. The effects of nutrient loadings should be evaluated (29) prior to future disposal in Clear Lake. Environmental risks could be minimized if: 1) sediment chemistry and/or elutriate tests were performed prior to disposal site selection, 2) algal growth studies were performed if disposal were proposed for periods of warm water temperatures, 3) shallow or poorly circulating areas were avoided, and 4) disposal occurred during periods of cool water temperatures.

The sparse sediment chemistry data for Cedar Bayou (Table IV-4) indicates that nutrient and metal contamination may cause undesirable effects during disposal operations. The evaluations suggested above for Clear Lake and the Houston Ship Channel should be used prior to disposal site selection in Cedar Bayou. The critical habitats of Table IV-7 should be outside the proposed affected area whether confined or open water sites are proposed.

The detremental physical effects of confined disposal can be minimized in Cedar Bayou if the physical considerations discussed from the ship channel are followed. For the open water sites of both Cedar Bayou and Clear Lake, environmental risks can be minimized prior to site selection if: 1) the effects of currents on the transport of the material are predicted, 2) the critical environments (Table IV-7) receive disposal material neither directly nor indirectly (by current transport), and 3) alternative land sites were selected to replace open water site.

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CHAPTER V - PRELIMINARY ASSESSMENT OF BENTHAL OXYGEN DEMAND

Scope and Objectives

The accumulation of benthal deposits can represent a significant oxygen sink and source of pollutional loading under highly developed urban or agricultural settings. The assessment of the magnitude and distribution of this benthal oxygen demand is particularly important in the Houston-Galveston Area Council 208 planning area.

Numerous investigators have quantified the oxygen demand of sediments. Further, direct measurements of benthal demand have been made for Houston Ship Channel sludge by Reynolds et al. (1) These existing studies should provide the basis for evaluation of the extent of the benthal oxygen demand as a non-point source in the planning area and facilitate preliminary mapping of such deposits.

The rigorous mathematical formulation of the benthal flux in a section-mean dissolved oxygen model is examined. Discussion of both a one-dimensional and two-dimensional model of the oxygen balance in the Houston Ship Channel is presented. Example computations are reveiwed for both techniques.

Summary and Conclusions

Benthal oxygen demand is a significant sink of dissolved oxygen in the Houston-Galveston Area Council 208 planning area, particularly in the Houston Ship Channel. Direct measurements of oxygen demand characterizing the sediments of the Ship Channel have been executed by Reynolds, et al. (1), supplying invaluable data to the present investigation. Further, characteristics of benthal deposits in lateral embayments have been reported by Hutton et al. (1970). (2) In conjunction with observations from numerous other investigations of benthal demand in a variety of locations, this data permits preliminary mapping of oxygen demanding material in the study area. The measured rate of oxygen consumption of Ship Channel sediments ranged from 0.12 to 0.22 g.m^2/hr, while lateral embayments on the Channel were assigned an estimated demand of 0.1 g/m^2/hr. An estimated average demand of 0.15 g/m^2/hr was assessed other streams and bayous in the study area.

Introduction

Although frequently assumed negligible in non-rigorous computations of the dissolved oxygen-biochemical oxygen demand balance in hydrographic studies, the potential importance of the benthal oxygen demand is well documented in the literature. Moreover, this importance is enhanced in water bodies subjected to agricultural, municipal, or industrial waste loadings - situations of particular concern in the Houston-Galveston Area Council 208 planning area. Bottom deposits may originate from a variety of sources, their accumulation augmented as a consequence of urbanization and industrial effluents and runoff from both urban and rural watersheds are often characterized by significant loads of settleable organic matter. Periods of heavy precipitation and concumitant stormwater runoff surges often contribute increased loadings on the system through transport of nuisance materials and bypass of untreated wastewater to the receiving stream. Additionally, the resultant elevated flowrates in the watercourse may be of sufficient magnitude to effect scour of previously deposited sediments, which in suspension may materially increase the oxygen demand upon the system.

The exertion of an oxygen demand by benthal deposits may occur in a twofold manner:

(i) Release of soluble oxygen-demanding constituents to the overlying water column, including reduced products of anaerobic bacterial decomposition and chemical reaction.

(ii) Respiratory requirements of aerobic microorganisms situated in the upper layer of sediment.

Typically, bottom deposits are assumed to be comprised of two zones, the upper aerobic, the lower anaerobic. The aerobic zone is exposed to the water-mud interface and encompasses only the top one or two centimeters of sediment. Existence of an aerobic layer is of course contingent upon the presence of oxygen in the overlying water column. A diverse community of microorganisms, including algae and heterotrophic and autotrophic bacteria, may populate this layer and consume oxygen in metabolic processes. If turbulence is of sufficient magnitude, benthal material may be scoured and resuspended in water column, thus increasing the overall biochemical oxygen demand.

Nutrients and products of decomposition from the anoxic zone diffuse upward into the aerobic layer and the overlying water. These substances may exert a chemical oxygen demand as well as a biochemical oxygen demand. The utilization of these soluble organics and nutrients by aerobic microorganisms and the oxidation of reduced products contribute to the total benthal oxygen demand. In fact, the oxygen demand of the bottom deposits is controlled by the upward diffusion of oxidizable substances through the interstitial pores of the sediment rather than the downward diffusion of dissolved oxygen. This conclusion may be verified with Fick's law of diffusion. (3)

Benthal deposits typically harbor a diverse spectrum of organisms. The chemosynthetic autotrophic bacteria of genera *Nitrosomonas* and *Nitrobacter* are frequently among the inhabitants. If a sufficient population exists, these microorganisms can esert a significant oxygen demand through the process of nitrification. Nitrification is the bacterial oxidation of ammonia nitrogen to first nitrite and then nitrate. Thus, if high instream concentrations of ammonia occur, as is often the case in polluted waterbodies, oxygen consumption through nitrification may be potentially significant. Nitrifier counts from sediment samples of the Houston Ship Channel are presented in Table V-1. These data were obtained as a part of a recent study of nitrification processes in the Channel supported by Du Pont. (4, 5)

Description of Methodology

Direct Measurements of Benthal Oxygen Demand. Numerous investigators have studied the oxygen demand of sediments, both in the laboratory and *in situ*. Laboratory studies have been conducted employing both batch and continuous systems with respect to the overlying water. Instream investigations have been performed with both enclosed and flow-through apparatus. A compendium of direct measurements of oxygen demand is presented in Table V-2. A diverse spectrum of sediments have been sampled, originating from rivers, lakes, and estuaries in varied states of productivity. Several investigators have synthesized simulated sludges for experimentation, often utilizing wastewater solids as a primary constituent. Results of uptake determinations (see Table V-2) exhibit considerable variation with no consistent correlation to the type of waterbody from which the benthal samples were derived.

Several types of apparatus have been employed in determinations of uptake rates. The mud core respirometer, a laboratory device of varying configuration and complexity, has been utilized in the majority of studies. Generally, a cylindrical reaction vessel holds the sediment sample and overlying water. With respect to the supernatant, both mixed and unmixed, and batch and continuous flow systems have been employed.

In situ studies are often performed with some form of chamber respirometer, an enclosure of varied configuration which rests atop the benthal layer, entrapping a small volume of the overlying water. Circulation may be provided by stirring or pumping apparatus Dissolved oxygen is monitored by an affixed electrode. A recent innovation *in situ* technique is the tunnel respirometer, wherein a plastic tunnel

TABLE V-1

NITRIFIER COUNTS IN HOUSTON SHIP CHANNEL SEDIMENT*

Sta. No.**	Date	VS (% of TS)	Ammonia-Oxidizers (No./gm)	Nitrite-Oxidizers (No./gm)
2	13 May 76	-	7.02×10^2	2.31×10^2
8	13 May 76	-	3.03×10^3	1.34×10^4
2	31 Aug 76	0.56	1.02×10^4	2.25×10^2
3	31 Aug 76	11.67	1.11×10^6	4.03×10^3
8	31 Aug 76	11.90	2.72×10^4	7.22×10^2
B1	31 Aug 76	8.47	2.63×10^5	2.74×10^3
B2	31 Aug 76	9.15	4.67×10^5	2.35×10^3
B3	31 Aug 76	7.69	8.07×10^4	4.92×10^3

* Analyses by Espey, Huston & Assoc., Inc.

** Sta. 2 near mouth of San Jacinto Bay
Sta. 3 upstream of Scott Bay
Sta. 8 near confluence with Greens Bayou
Sta. B1 in San Jacinto Bay
Sta. B2 in Scott Bay
Sta. B3 in Burnett Bay

TABLE V-2

MEASUREMENTS OF BENTHAL OXYGEN DEMAND

Oxygen Uptake Rate ($g\ O_2/m^2/hr$)	Sediment Source	Temperature (°C)	Depth of Sediment (cm)	Reference
0.19-0.31	Simulated Sludge	22	2-13	Fillos and Molof (1972)
0.119	Paper Waste	25	~1	Hanes and Irvin (1966)
.21-.54	Simulated Sludge	20	7.62	Ogunrombi and Dobbins (1970)
.045-.194	Simulated Sludge	20-25	1.4-10.2	Fair et al. (1941)
.078-0.113	Muddy River	20-24	13	Fillos and Swanson (1975)
0.14-0.25	Spring Creek	20	2-25	McDonnell and Hall (1967)
.013-.06	Running Waters	-	-	Edberg and Hofsten (1973)
.092	Ivel River	-	-	Knowles et al. (1962)
0.22-1.59	Running Waters	-	-	James (1974)
.039-.10	River Anker	-	-	Bradley and James (1968)
.08	River Hiz	20	2.1-10.2	Edwards and Rolley (1965)
0.2	River Gade	20	4-17	Edwards and Rolley (1965)
0.072	Lake Warner	24	13	Fillos and Swanson (1975)

TABLE V-2
(contd.)
MEASUREMENTS OF BENTHAL OXYGEN DEMAND

Oxygen Uptake Rate ($g\ O_2/m^2/hr$)	Sediment Source	Temperature (°C)	Depth of Sediment	Reference
.018-.108	Various Lakes	-	-	Edberg and Hofsten (1973)
.006-.044	Various Lakes	-	-	Hayes and MacAulay (1959)
.14± 10%	Yaquina Estuary	20	-	Martin and Bella (1971)
0.12-0.22	Houston Ship Channel	32	-	Reynolds et al. (1973)
.038-.125	Baltic Sea	-	-	Edenberg and Hofsten (1973)

is constucted upon the streambed, the longitudinal axis oriented parallel to the direction of flow. This system, where applicable, enables calculation of oxygen uptake under the ambient hydraulic conditions.

Considerable attention has focused upon the effects of certain physiochemical parameters upon benthal oxygen demand. In particular associations with sludge depth, temperature, and dissolved oxygen have been examined. Also of interest are investigations of nutrient sediment interactions. Each of these topics is discussed in greater detail in subsequent sections.

Effect of Sludge Depth. It is generally accepted that benthal oxygen demand is dependent on sediment depth to some limiting value, supplemental depth in excess of this value having no effect. Based on experimentation with wastewater sludge depths of 0.1 to 4 cm at 22 u.c., Baity (6) proposed the empirical relationship,

$$U = 2{,}700\ X^{0.485}$$

where U represents the rate of oxygen demand ($mg/m^2/day$) and X is the depth of sludge (cm). A critical sludge depth of 3 to 4 inches (7.6 to 10.2 cm), above which the oxygen uptake rate is independent of sludge depth, is suggested by the data of Fillos and Molof. (7) Supportive evidence includes an assay of the vertical distribution of bacteria in lake sediments, indicating no significant decline in bacterial numbers down to a depth of about 10 cm, below which populations decreased logarithmically. (7) Bacterial counts by Hayes and Anthony (8) suggest a critical limit of 5 cm. Martin and Bella (9) found no predictable variation of oxygen uptake rate with depths of deposit ranging from 2 to 12 inches (5.1 to 30.5 cm). Regression analyses of data from the River Hiz and the River Gade in England indicated no significant change in oxygen consumption with mud depth, utilizing sample depths of 2 to 10 cm from the former and 4 to 17 cm from the latter, (10) These results suggest an active zone incorporating the uppermost 2-4 cm of sediment.

Effect of Temperature. Numerous investigators have sought to extablish a relationship between benthal oxygen demand and temperature. Observed seasonal changes in oxygen consumption may reflect population changes in the benthos, which may be affected by temperature, as well as supply of nutrients and hydraulic conditions. Temperature also exerts an influence on the rates of diffusion processes, for instance, diffusion of oxygen into the aerobic layer of sediment, diffusion of soluble substrate to microorganisms and transport of reduced substances from the anaerobic mud.

Generally, benthal oxygen demand increases with temperature elevation, often exhibiting an approximate adherance to the common maxim specifying a doubling of biological activity in response to a $10^{\circ}C$ rise in temperature. Reynolds et al. (1) applied data from the Houston Ship channel to a temperature correction equation of the form:

$$U_2 = U_1 \Theta^{(T_2 - T_1)}$$

where U_1 and U_2 are the benthic demands ($g/m^2/hr$) at temperatures T_1 and T_2 (degrees Celsius). The parameter Θ was found to be 1.055. Determinations of Θ for several studies are listed in Table V-3. It should be noted that Adberg and Hofsten (11) found the temperature coefficient to fall with increasing temperature, based on respiration of cultures of cellolytic bacteria.

Effect of Dissolved Oxygen. Some controversy exists concerning the dependency of benthal oxygen upon the concentration of dissolved oxygen in the overlying water column. Data from several studies, such as those of Baity (6) and Fair et al. (12) with settled sewage sludge, indicate that the oxygen demand is independent of the dissolved oxygen concentration, albeit with the qualification of a limiting dissolved oxygen requirement on the order of 1 mg/l. This limiting value, not coincidentally, approaches the minimum level of dissolved oxygen necesarry to support aerobic bacterial respiration and metabolism. Fillos and Molof (7) proposed the following empirical expression in light of their experiments with a simulated sludge:

$$U = A \quad (1 - e^{-1.22u.c.})$$

in which the benthal oxygen uptake rate U is related to the dissolved oxygen concentration C in the overlying water (A is a constant whose value depends on the nature of the deposits). Thus, the relationship indicates that the benthal demand is relatively independent of dissolved oxygen concentration in excess of 2 mg/l, but decreases at lower concentrations.

Conversely, research by Edwards and Rolley (10) using river muds revealed a correlation of benthal uptake rate with oxygen concentration up to about 8 to 10 mg/l. An explanation is offered by McDonnell and Hall (13), who suggest that the dependency is primarily a function of the respiration of the macro-invertebrate population within the sediment sample. Studies that demonstrated no relationship between uptake and oxygen content reputedly employed samples that contained no invertebrates, while such organisms did inhabit sediments that exhibited a dependence of oxygen demand on dissolved oxygen. Oxygen consumption of mud cores from the River Colne (England), containing 39,000 Chironomus riparius larvae/m^2, and the River Tark (England), containing 140,000 larvae/m^2, was dependent on dissolved oxygen concentration in the supernatant water up to about 4 mg/l. (14)

TABLE V-3

TYPICAL VALUES OF Θ

Θ	Temperature Range (^{o}C)	Sediment Source	Reference
1.055	15-32	Ship Channel	Reynolds et al. (1973)
1.069	5-25	Stream	McDonnell and Hall (1967)
1.080	10-20	River	Edwards and Rolley (1965)
1.067	10-20	River	Edwards and Rolley (1965)
1.130	5-15	Simulated	Edberg and Hofsten (1973)
1.080	10-20	Simulated	Edberg and Hofsten (1973)
1.040	15-25	Simulated	Edberg and Hofsten (1973)
1.067		River	Fair et al. (1941)
1.078		River	Fair et al. (1941)

McDonnel and Hall (13) and Edwards and Rolley (10) found oxygen uptake increasing with dissolved oxygen up to about 8 mg/l in benthal samples containing significant populations of macroinvertebrates. But Fillos and Molof (7) counter that results showing oxygen uptake rate increasing with increasing oxygen concentration were derived from batch systems with respect to both sludge and the overlying water, therefore the systems never acclimate to the desired dissolved oxygen level as it is continuously changing.

Edwards and Rolley (10) suggest that the relationship between oxygen consumption and demand be described by a logarithmic transformation:

$$U = aC^b$$

where U represents the oxygen consumption, C is the oxygen concentration in the overlying water, and a and b are constants. Such a relationship is appropriate for descriptions of systems where simultaneous reaction and diffusion occur and has also been shown to describe the oxygen consumption of macrophytes. McDonell and Hall (13) indicate the existence of a composite benthal oxygen demand, composed of constant and variable elements. The constant component is assumed attributable to microbial respiration, which is independent of oxygen concentration above about 0.5 mg/l, and chemical oxidation. The variable component represents respiration of invertebrates and algae, which is dependent on oxygen concentration up to some limiting value. Mathematically,

$$U_t = U_c + U_v \ (1-e^{-kc})$$

where U_t is the total observed oxygen uptake ($g/m^2/hr$), U_c the constant component ($g/m^2/hr$), U_c the variable component ($g/m^2/hr$), the oxygen concentration (mg/l) and k a constant. In general, the respiration of invertebrates may account for 40-55 percent of the total benthal demand.

Nutrient - Sediment Interactions. The interactions of sediments and nutrients in the overlying water may affect the overall water quality of a waterbody. Depending on whether benthal deposits function as a source or sink for nutrients, concentrations of these constituents in the water column will increase or decrease. Productivity may respond to such stimuli, with potentially significant implication on the dissolved oxygen budget of the waterbody.

Laboratory investigations by Fillos and Biswas (15) employing sediment samples from eutrophic Lake Mohegan in New York indicated that sediments act as a sink for phosphorous in an aerobic environment. But under anoxic conditions, sediments function as a source for phosphorus until a phosphate concentration of 1.0 to

1.4 mg/l is attained in the overlying water, above which the benthal deposits again act as a sink for the nutrient. This phenomenon was corroborated in a study by Fillos and Swanson (16) in which an apparently steady-state level of 1.9 to 2.1 mg/l phosphate was reached in anaerobic supernatant above sediments extracted from the Muddy River in Boston, Massachusetts. Similarly, the release rate of phosphate was shown in increase when dissolved oxygen was lowered to 1.5 mg/l or lower, employing a simulated sludge composed of sand and primary wastewater solids. (7) Fillos and Swanson (16) and Fillos and Biswas (15) also observed maximum release rates of phosphate under anaerobic conditions, with the release rate decreasing as the phosphate concentration in the overlying water increases. Explanation of the observed nutrient absorption by sediments in an aerobic environment focuses upon the thin aerobic layer of the bottom deposits. The sorption capacity is predominately credited to the presence of colloidal ferric complexes. Under anoxic conditions, the sorption capacity is abolished as the ferric complexes are reduced, thus releasing the complexed nutrients. (17)

The release rate of ammonia under anaerobic conditions was found to be roughly triple the rate observed above 2 mg/l dissolved oxygen by Fillos and Molof. (7) Fillos and Swanson (16) discovered no correlation between dissolved oxygen concentration and ammonia release rate.

Total iron release rate was generally related to the behavior of phosphate release in the study of Fillos and Swanson. (16) Calcium and aluminum release rates demonstrated no discernable trends as concentration variations were insufficiently small.

Assessment of Benthal Demand in the H-GAC Planning Area

The magnitude of the benthal oxygen demand in any given watercourse in the planning area may be influenced by external factors such as the nature and location of wastewater outfalls, wastewater treatment technology employed, stormwater loadings, and general land use patterns. Point source discharges to the receiving stream are often of primary interest, as segments immediately downstream are potential sites of sludge bank formation, particularly when an effluent containing high concentrations of settleable constituents is introduced into a region of low velocity stream flow, facilitating deposition of the suspended load. In this respect, the wastewater treatment technology employed may affect the benthal demand of the receiving stream to a certain extent. Increased removal of insoluble matter in the treatment system would diminish the loading to the stream and subsequent buildup of bottom deposits. However, continued advances in treatment technology, such as progression from "best, practicable control technology currently available" to "best available technology," may represent a situation of diminishing returns. Recall that oxygen uptake is not a function of sludge depth, therefore, reduction in the discharge of settleable matter with the intention of reduction of benthal deposits may not bring about the desired reduction of oxygen uptake. Even supposing complete removal of settleable matter from point source discharges, a more than adequate supply of benthal material would be contributed by nonpoint sources such as stormwater runoff. Even though scouring occurs the material only moves downstream and new material is added. Thus, since sources of benthal load are manifold, elimination or control of only one contributor may have negligible effect on the overall benthal oxygen demand.

Specific relationships between sludge accumulation and land use changes are without documentation, but certain observations are appropriate. Urbanization generally augments the magnitude of stormwater runoff, increases the transport of pollutants from the surface of the watershed, and effects a degradation of runoff water quality. Thus, sludge accumulation in the receiving stream is undoubtedly accelerated. Utilization of land for agriculture and grazing may result in elevated loadings of silt, nutrients, organics, and other constituents in stromwater runoff, and similarily expedite benthal deposition.

The preceding discussion of various factors and relationships effecting benthal load is generally speculative. However, quantitative analysis of these interactive analysis of these interactions is not currently possible, as substantive field investigations and laboratory research are lacking.

Houston Ship Channel. Of particular importance to the Houston-Galveston Area Council 208 area is a study by Reynolds, et al. (1) in which laboratory measurements of benthal oxygen demand were conducted on sediment samples obtained from the Houston Ship Channel (see Table V-4). Higher values of oxygen uptake are evident for the upper Channel, compared to the lower reaches. This is no doubt indicative of the greater municipal and industrial waste loadings discharged into the upper portion of the waterway. Although no data on the lateral distribution of benthal demand are available these volumes were assumed to be uniform, at least over the dredged portion of the cross section, because of lack of better information.

A high linear correlation was observed between benthal demand and BOD_5 of the sludge:

$$R = 0.035 + 3.45 \times 10^6 \text{ (L)}$$

where R represents the benthal oxygen demand in $g/m^2/hr$ at 32C and L is the five-day biochemical oxygen demand in mg/kg (dry weight) at 20C. The temperature dependency of the oxygen demand was

TABLE V-4

BENTHAL OXYGEN DEMAND
HOUSTON SHIP CHANNEL SEDIMENTS*

Miles Upstream From Morgans Point	Oxygen Uptake	
	$g/m^2/hr$	$g/m^2/day$
0	.12	2.88
10	.12	2.88
12	.125	3.00
14	.13	3.12
16	.15	3.60
18	.19	4.56
20	.22	5.28
22	.20	4.80
24	.16	3.84

* measurements at 32C, from Reynolds et al. (1)

formulated as follows:

$$R_2 = R_1 (1.055)^{T_2 - T_1} .$$

where R_1 and R_2 are the benthic demands (g/m^2/hr) at temperatures T_1 and T_2 (degrees Celsius), respectively.

Little direct information concerning the sludge demand in the lateral bayous and embayments on the Ship Channel is available, however several observations are pertinent. Volumes of municipal and industrial discharge into the lateral reaches are considerably less than those in the Channel proper, hence a smaller benthal demand may be expected for these regions. A notable exception is Scott Bay. Sludge samples were collected by Hutton et al. (2) in Burnett, Scott, and upper San Jacinto Bay. In Burnett and Upper San Jacinto Bays the values of BOD_5, COD, and volatile solids of the sludge samples were found to be respectively one-tenth, one-half, and one-fifth of the typical magnitudes in the corresponding reach of the channel. In Scott Bay, which receives significant industrial waste discharges, the BOD_5, COD, and volatile solids were respectively one-third, one-half, and one-half of those typical of the Channel. If the relation of Reynolds et al. (1) correlating benthal demand and BOD_5 of the sludge is adopted, oxygen uptake inthe lateral bays is estimated to be an order of magnitude less than typical Channel values. But this seems an underestimate, based on literature values (see Table V-2), indicating that the uptake-BOD_5 dependency does not remain linear at lower values. Combining all of these considerations, benthal demand in the lateral embayments is estimated to be roughly 0.1 g/m^2/hr at 32C.

Area Streams and Bayous. While direct measurements are available for the Houston Ship Channel, benthal demand on other streams and bayous in the H-GAC planning area must be estimated. Typical attributes of area watercourses include low velocity, high turbidity, and a mud or clay channel. Point and nonpoint pollutant loadings have contributed to a general degradation of water quality. An average benthal demand of 0.15 g/m^2/hr at 32C is estimated for area watercourses, a tentative approximation based on the literature review summarized in Table V-2. Deviations from this average value may be justified in certain situations, such as a stream segment immediately below a wastewater outfall where an elevated demand, perhaps on the order of 0.2/g/m^2/hr, may be appropriate, or a relatively unpolluted reach where 0.1/g/m^2/hr may more closely approximate the uptake rate. But in lieu of direct field measurements, methodical adherance to the estimated average demand would probably be judicious.

Mathematical Implementation

Formulation. The complete continuity equation for dissolved oxygen c is

$$\frac{dc}{dt} = - \frac{\partial}{\partial z} \frac{F_z}{\rho} + Kc + P$$

where F_z is the vertical flux of DO (neglecting lateral and horizontal fluxes) and Kc + P is the volume generation of DO due to first order and zeroth order processes. The vertical flux is composed of

internal fluxes: molecular diffusion $-\varepsilon \frac{\partial c}{\partial z}$

turbulent diffusion $-\varepsilon \frac{\partial c}{\partial z}$

boundary fluxes: surface reaeration $\propto c - c_s$ (at surface)

benthal flux F_b (positive upwards)

The geometry of the problem is sketched in Figure V-1. We wish to transform (1) to an equation in the section-mean c

$$\bar{c}(x) = \frac{\displaystyle\int_{y_o}^{y_o+W} \int_{h-d}^{h} c(x,y,z)\, dz\, dy}{\displaystyle\int_{y_o}^{y_o+W} d(x,y)\, dy}$$

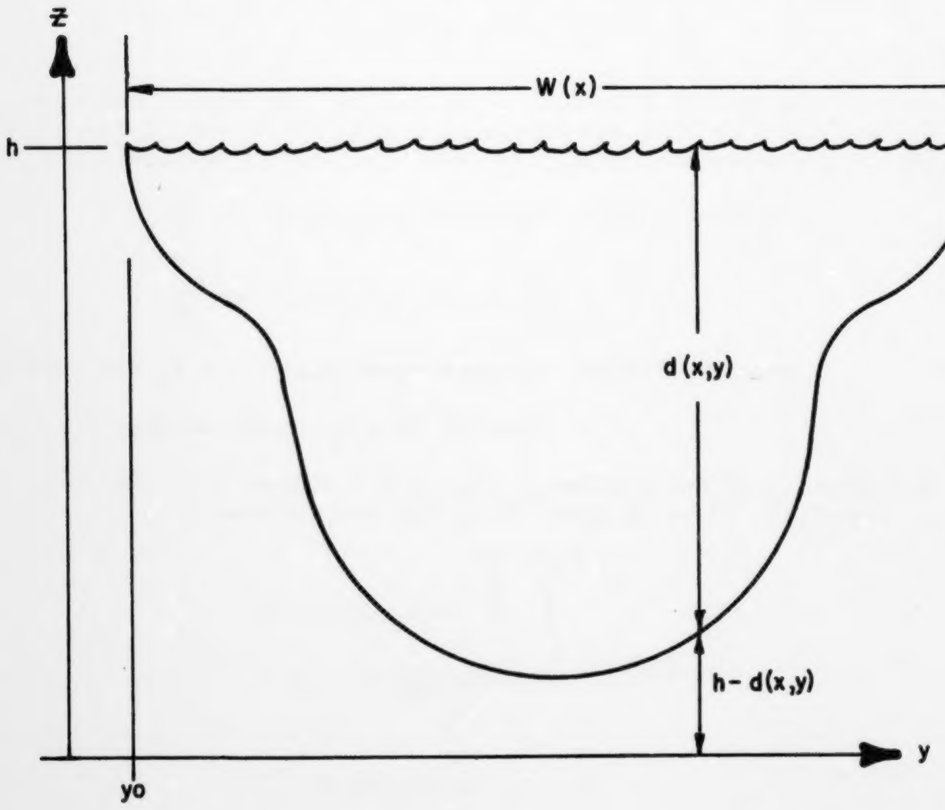
as a function of longitudinal coordinate x only. We note that the cross-sectional area A and mean depth D are given by

$$A = \int_{y_o}^{y_o+W} d(x,y)\, dy \,, \quad D = \frac{1}{W} \int_{y_o}^{y_o+W} d(x,y)\, dy$$

so that WD = A. Here A, W, y_o and D are functions of x only. Upon integrating (1) with respect to z from h-d to h and with respect to y from y_o to y_o+W have

FIGURE V-1

DEFINITION SKETCH


z
W (x)
h
d (x,y)
h- d(x,y)
y
yo

$$B + \frac{\partial}{\partial t}\int_{y_o}^{y_o+W}\int_{h-d}^{h} c\;dz\;dy + \frac{\partial}{\partial x}\int_{y_o}^{y_o+W}\int_{h-d}^{h} uc\;dx\;dy = K\int_{y_o}^{y_o+W}\int_{h-d}^{h} c\;dx\;dy$$

$$-\int_{y_o}^{y_o+W}\frac{F_s}{\rho}\;dy + \int_{y_o}^{y_o+W}\frac{F_b}{\rho}\;dy + A\bar{P}$$

in which boundary conditions of zero advective flux have been used and in which B denotes the boundary gradient terms arising from Leibniz' rule. Writing $\overline{uc}$ and $\overline{uc} + \bar{u}'\bar{c}'$ in the usual manner and approximating $\frac{F_s}{\rho} = K_a(\bar{c}-\bar{c}_s)$ as is the convention, this

becomes

$$\frac{\partial \bar{c}}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}A\,\bar{u}\bar{c} + \left(\frac{B}{A}+\frac{e}{A}\right) = K\bar{c} + K_a(\bar{c}_s-\bar{c})$$

$$+ \bar{P} + \frac{1}{A}\int_{y_o}^{y_o+W}\frac{1}{\rho}F_s\;dy$$

Finally, the first-order term is generally a deoxygenation with rate $-K_d$, and the benthal flux is generally a downward mass flux of rate S (mass of O_2/unit area/unit time). Then

$$\frac{\partial \bar{c}}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}A\,\bar{u}\bar{c} + \left(\frac{B}{A}+\frac{e}{A}\right) = -K_d\bar{c} + \bar{P}$$

$$+ K_a(c_s-\bar{c}) - \frac{1}{\rho D}\left\{\frac{1}{W}\int_{y_o}^{y_o+W}S(y)dy\right\} \qquad (2)$$

The terms $(\frac{B}{A} + \frac{e}{A})$ generally appear as a disperson term, but this need not concern us here.

The benthal sink in equation (2) is a lateral average of the flux rate S divided by density and the lateral-mean depth. This is the term S_b in the one-dimensional model, e.g. in the Hydroscience Ship Channel model,

$$S_b \equiv \frac{1}{W} \int_{y_o}^{y_o + W} S(y)\, dy$$

In order to evaluate the S_b for input to this model, one must have the lateral distribution of S across the channel. If the sludge characteristics are laterally uniform, as is probably the case for the H-GAC segments, then $S_b \cong S(y_o + \frac{W}{z})$, the centerline value.

Model Calculations. In 1968 the Texas Water Quality Board initiated the Galveston Bay Project, a multi-disiplined study of the Galveston Bay system with the objective of developing sufficient information about the system to formulate an overall management plan. The study was brought to a successful conclusion in 1975 with the publication of the project report. (18) One of the products of the Galveston Bay Project is a set of numerical models of bay hydrodynamics, BOD, DO, salinity and temperature, and of the BOD - DO balance of the Houston Ship Channel. The latter model is of particular utility for the present investigations. Two models have been in extensive use by the Galveston Bay Project for calculations of DO/BOD in the HSC: a one-dimensional (1-d) model and a two-dimensional BOD/DO model. Differences between the models are:

(i) 2-d model is a finite-difference solution of the (steady-state) mass balance equation. In the Channel portion of the model it is essentially one-dimensional (since there are no lateral transports), and represents linear distance up the channel. The 1-d Hydroscience model is a continuous analytic solution to the 1-d steady-state equation within each segment, the segment solutions being patched together at their endpoints by the requirement that concentrations be continuous.

(ii) The 2-d model has only one lateral connecting waterbody in the Ship Channel portion, viz. the San Jacinto River. The 1-d Hydroscience model includes 14 lateral bays and inflows.

(iii) Loads may be introduced into the 1-d model only at the segment junctions, i.e. only at 14 points. Loads may be introduced into the 2-d model every nautical mile.

(iv) The boundary conditions at Morgan Point are determined in the 2-d model by the interaction with the rest of Galveston Bay. In the 1-d model, it is determined by the interaction with the subvolume of Galveston Bay assigned to Segment 28.

Insofar as benthal deficit is concerned, the only significant differences in the model calculations should arise from (ii) and (iv) above. Otherwise the two models work the same problem (albeit with different formulations) and should give roughly equivalent results. (Some differences will still result from the intrinsic incompatibility of the 1-d segmentation and the 2-d cell structrue, and from numerical truncation errors, but these should be minor.) The one-dimensional Hydroscience model was employed to demonstrate the impact of the benthal demand on the instream DO concentration under various combinations of ambient parameters. It should be noted that variation of the model parameters, in addition to S_b *per se*, can produce a notable range of variation in the benthal deficit. The results of this study are shown in Figures V-2 to V-5. A simple standard calculation was made assuming

(i) constant inflow of 100 cfs, in Buffalo Bayou,

(ii) K_a (20C) = .05 day^{-1} everywhere, scaled to 31C with $\Theta = 1.02$ (K_a is defined, on page V-17, as reaeration coefficients. Discussion of reaeration is beyond the scope of this document),

(iii) dispersion $E_x = 10\ \text{mi}^2/\text{day}$ everwhere ($\frac{B}{A} + \frac{e}{\Delta}\ \frac{1}{A}\frac{\partial}{\partial x} AE_x \frac{\partial C}{\partial x}$ by definition. Dispersion is diccussed in standard references on stream modeling and is beyond scope of present document),

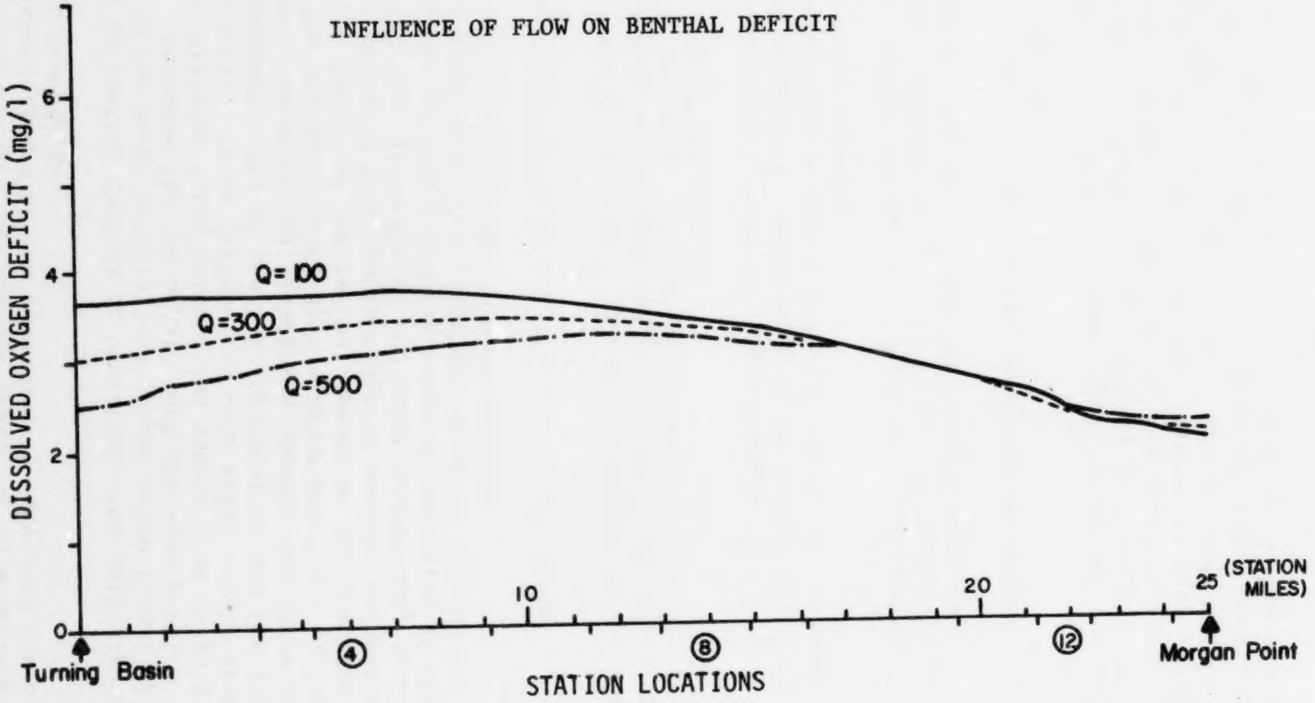
(iv) a constant benthal sink equal to 2 g/m^2/day at 20C, depth-normalized to be equal to .354 mg/l/day, in the Channel and zero in the off-channel segments.

Then the effect of variation in individual parameters on the benthal deficit was investigated.

In Figure V-2 and V-3 are shown respectively and the influence of varying Q and E_x. Since the only inflow is through Buffalo Bayou, the response to Q is largely confined to the upper Channel. For this simulation problem, all flows were assumed to pass through Buffalo Bayou, WLOG, Sensitivity Studies are not affected by this. When we simulate a real condition, inflows are input where appropriate. Figure V-4 shows the response to variation in K_a, which is substantial.

FIGURE V-2

INFLUENCE OF FLOW ON BENTHAL DEFICIT



Note: This is a concentration, not a rate, and therefore cannot be converted to lbs/day. This is the effect of the benthal load (lbs/hr) on DO concentration (mg/l).

These are section means as defined on page V-22.

FIGURE V-3

INFLUENCE OF DISPERSION ON BENTHAL DEFICIT

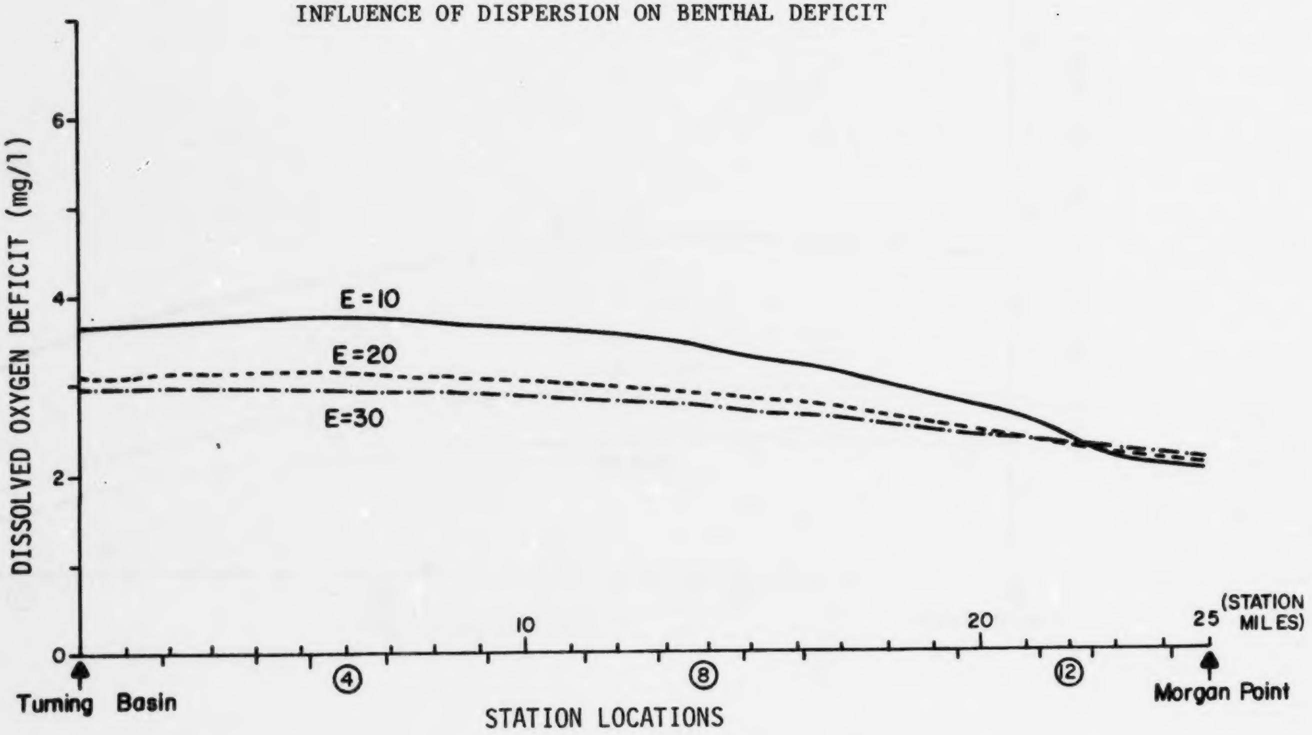
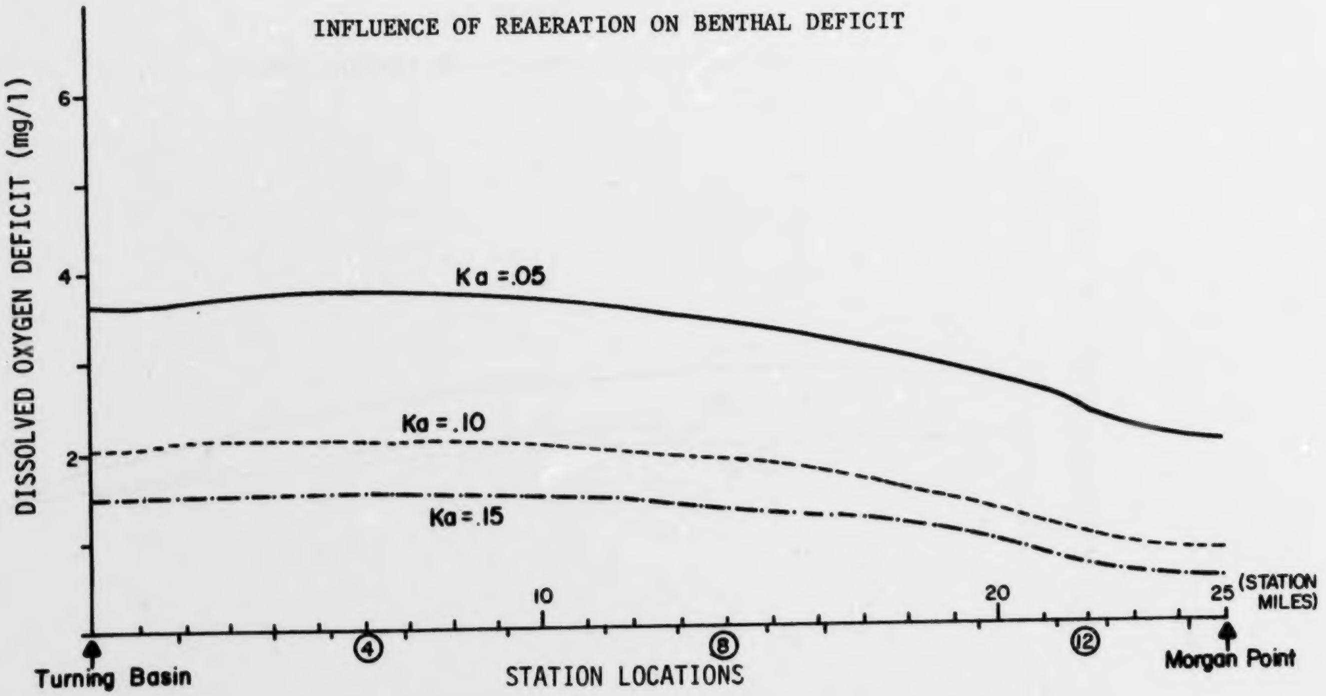


FIGURE V- 4

INFLUENCE OF REAERATION ON BENTHAL DEFICIT



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APPENDIX A

QUANTITY/QUALITY SUMMARY OF RECORDED RUNOFF EVENTS

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (34)
FOR
39th AND HOLDREGE
LINCOLN, NEBRASKA

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.		
		T.S.S.	B.O.D.	C.O.D.
4/15/72	.07	10.69	.78	4.25
4/27/72	.40	29.10	.48	6.62
5/23/72	.14	24.32	1.31	8.09
6/4/72	.04	10.04	.53	3.17
6/13/72	.09	12.91	1.25	7.50
6/16/72	.05	8.10	N.R.	1.77
7/4/72	.0003	.01	.006	.02
7/11/72	.01	.56	.80	3.48
7/26/72	.29	26.15	11.99	18.59
7/31/72	.03	1.63	N.R.	1.94
8/8/72	.18	40.96	N.R.	15.69
3/10/73	.97	196.22	.96	47.57
3/23/73	.68	83.52	1.97	19.82
4/19/73	.08	11.85	.52	3.67
5/21/73	.08	11.95	N.R.	8.67
6/2/73	.19	14.73	N.R.	5.83
6/4/73	.11	6.80	.71	3.34
7/3/73	.61	181.88	3.54	28.93

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (34)
FOR
63rd AND HOLDREGE
LINCOLN, NEBRASKA

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.		
		T.S.S.	B.O.D.	C.O.D.
4/15/72	.55	76.78	2.68	17.52
5/11/72	.78	113.55	1.27	23.15
7/7/72	.22	23.78	4.17	21.15
7/25/72	.13	5.66	5.33	8.46
7/31/72	.05	2.49	N.R.	13.32
3/10/73	.96	214.06	1.05	31.50
3/23/73	1.26	198.25	2.86	33.87
4/19/73	.09	13.70	.23	2.97
6/2/73	.26	28.18	N.R.	8.98
6/4/73	.05	4.47	.39	1.39
6/5/73	.06	8.97	N.R.	2.62
6/18/73	.07	28.30	.53	7.46
7/13/73	.47	N.R.	1.15	6.14
7/18/73	.21	N.R.	56.92	13.87

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (34)
FOR
78th AND A
LINCOLN, NEBRASKA

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.		
		T.S.S.	B.O.D.	C.O.D.
4/15/72	.03	6.25	.11	1.58
5/23/72	.08	34.89	.22	2.10
6/2/72	.02	4.86	N.R.	.46
6/4/72	.01	1.33	.024	.14
7/11/72	.03	1.16	.11	.34
7/25/72	.07	10.01	N.R.	.78
6/5/73	.002	.35	N.R.	.03
6/18/73	.01	2.67	.03	.21
6/30/73	.002	.53	.02	.07
7/17/73	.02	N.R.	.05	.20

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (22)
FOR
THIRD FORK
DURHAM, N.C.

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.							
		T.S.S.	B.O.D.	C.O.D.	KJELDAHL-N	P*	T.S.	V.S.	V.S.S.
10/23/71	.18	3.73	.55	.90	.04	.012	9.31	N.R.	N.R.
11/24/71	.02	1.38	N.R.	1.09	.03	.002	2.31	N.R.	N.R.
12/16/71	.004	.13	N.R.	.10	.009	.0004	.48	N.R.	N.R.
12/20/71	.14	N.R.	N.R.	4.15	N.R.	N.R.	N.R.	N.R.	N.R.
1/4/72	.04	4.10	.21	1.67	.01	.01	5.40	N.R.	N.R.
1/10/72	.19	26.10	.96	7.33	.09	.04	35.72	N.R.	N.R.
2/1/72	.82	277.71	N.R.	35.40	.09	.12	318.82	N.R.	N.R.
2/12/72	.40	113.77	N.R.	18.72	N.R.	N.R.	130.60	N.R.	N.R.
2/18/72	.17	N.R.	N.R.	5.77	.02	.02	N.R.	N.R.	N.R.
2/23/72	.02	3.72	N.R.	.96	.004	.004	6.37	N.R.	N.R.
2/26/72	.04	15.79	N.R.	2.87	N.R.	N.R.	N.R.	N.R.	N.R.
3/8/72	.01	.37	.05	.24	.002	.002	.98	.20	.04
3/16/72	.09	17.10	.51	4.95	.01	.02	21.65	5.05	3.14
3/31/72	.12	30.34	N.R.	3.61	N.R.	N.R.	30.83	4.09	2.62
4/12/72	.11	29.67	.51	3.15	N.R.	N.R.	N.R.	N.R.	4.04
5/3/72	.44	N.R.	N.R.	28.20	.07	.13	N.R.	N.R.	N.R.
5/14/72	.24	78.81	N.R.	5.94	.02	.03	84.41	7.82	5.83
5/22/72	.42	52.19	N.R.	3.48	.03	.06	95.78	9.90	7.27

* Total Phosphates

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (22)
FOR
THIRD FORK
DURHAM, N.C.

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.							
		T.S.S.	B.O.D.	C.O.D.	KJELDAHL-N	P*	T.S.	V.S.	V.S.S.
5/31/72	.03	8.30	.04	1.44	.005	.005	6.83	.8	.88
6/20/72	.06	23.52	.86	4.90	.013	.029	14.41	2.39	3.43
6/28/72	1.54	957.01	33.92	85.61	.15	.35	N.R.	N.R.	86.52
7/12/72	.09	11.49	1.87	2.45	.005	.011	12.01	3.17	.93
7/17/72	.13	82.43	2.34	10.98	.01	.04	93.42	12.55	9.08
7/31/72	.26	212.88	.96	12.81	.02	.05	N.R.	17.07	9.17
8/28/72	.0015	1.35	N.R.	N.R.	N.R.	N.R.	1.85	.10	.05
9/17/72	.60	389.62	5.75	37.0	.07	.12	500.12	39.30	30.63
9/21/72	.05	9.63	N.R.	1.79	.004	.004	10.95	1.56	.73
10/5/72	.54	172.33	15.39	16.79	.03	N.R.	191.34	23.29	13.33
11/14/72	.24	5.77	5.95	8.27	.02	.05	66.28	12.86	.87
11/30/72	.01	2.07	.10	.17	.0004	.001	2.62	.43	.24
1/19/73	.01	2.50	.09	.71	.001	.003	3.07	.59	.41
2/26/73	.03	5.37	.53	1.49	N.R.	N.R.	6.51	1.51	.75
3/21/73	.10	14.82	N.R.	2.29	.01	.01	16.15	3.94	2.36

* Total Phosphate

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (27)
FOR
P-10
WOODLANDS, TEXAS

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.							
		T.S.S.	B.O.D.	C.O.D.	NH_3-N	NITRATE	NITRITE	KJELEAHL-N	P *
12/5/74	.62	3.77	N.R.	8.72	.012	.002	N.R.	.12	.01
3/13/74	.06	.90	N.R.	.85	.001	.001	.00005	.02	.001
4/7/75	1.25	10.54		16.06	.02	.02	.001	.38	.02

* Total Phosphates

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (27)
FOR
P-30
WOODLANDS, TEXAS

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.								
		T.S.S.	B.O.D.	C.O.D.	NH_3-N	NITRATE	NITRITE	D.O.	K-N*	P**
1/18/74	1.30	69.04	N.R.	N.R.	.01	.008	N.R.	2.60	N.R.	N.R.
4/22/74	.003	.68	N.R.	.07	.0002	.0002	.00001	.003	.001	.0004
10/28/74	.54	35.87	N.R.	N.R.	.01	.004	N.R.	N.R.	N.R.	.01
4/7/75	1.57	60.72	N.R.	18.68	.05	.05	.004		.49	.03

* K-N - KJELDAHL-N
** P - Total Phosphates

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (27)
FOR
HUNTING BAYOU
HOUSTON, TX.

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.								
		T.S.S.	B.O.D.	C.O.D.	NH_3-N	NITRITE	NITRATE	K-N*	P**	D.O.
3/26/74	.26	11.37	1.22	5.76	.15	.004	.03	.2	.024	.28
4/11/74	.08	2.07	N.R.	1.73	.01	.001	.006	.03	.02	N.R.
5/8/75	.18	8.19	N.R.	7.10	.05	.002	.02	.13	.04	N.R.
6/30/75	.70	28.83	N.R.	12.77	.33	.007	.06	.63	.20	N.R.

* K-N - KJELDAHL-N
** P - Total Phosphates

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (28)
FOR
TEXAS TECH DATA
LUBBOCK, TEXAS

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.					
		T.S.S.	V.S.S.	B.O.D.	C.O.D.	NITRATE	TOTAL PHOSPHATES
8/23/71	.07	5.14	1.96	N.R.	22.86	N.R.	N.R.
9/22/71	.04	1.68	.13	.043	1.70	.00072	.00053
10/17/71	.02	3.69	.95	N.R.	4.10	.00052	.00024
10/25/71	.03	2.69	.66	.104	2.34	.00077	.00031
5/3/72	.02	42.75	2.13	.60	3.99	.0023	.00025
5/4/72	.01	2.69	.18	N.R.	.36	.00033	.00024
5/5/72	.06	29.73	1.79	.45	4.22	.003	.002
	.09	75.17	4.10	.525	8.57	.00563	.00249
6/29/72	.02	6,45	.72	.10	1.47	.00042	.00017
6/30/72	.02	5.35	.26	.08	.69	.00088	.00079
	.04	11.8	.96	.18	2.16	.00130	.00096
7/3/72	.08	26.32	2.35	N.R.	1.56	.0027	.0018
7/4/72	.07	32.96	2.92	N.R.	2.50	.0037	.0015
	.15	59.28	5.27	N.R.	4.06	.0064	.0033

QUANTITY/QUALITY SUMMARY OF RUNOFF EVENTS (24)
FOR
SELBY STREET OUTFALL
SAN FRANCISCO, CA.

DATE OF EVENT	TOTAL VOLUME OF RUNOFF (in.)	TOTAL POUNDS OF POLLUTANT GENERATED IN LBS./AC.						
		T.S.S.	B.O.D.	C.O.D.	V.S.S.	K-N *	P **	NH_3-N
11/6/66	.24	15.43	1.86	11.97	5.08	.36	.06	.03
11/15/66	.09	2.04	.9	3.41	.89	.29	.03	.18
11/14/66	.06	1.51	.78	3.03	.75	.10	.02	.02
1/20/07	2.96	111.84	15.95	75.66	30.13	1.27	.38	N.R.
1/23/67	.52	23.58	4.09	14.08	8.09	.35	.10	N.R.
2/24/67	.03	5.22	1.88	6.06	3.08	.17	.58	.03
3/10/67	.29	43.55	5.40	17.95	15.33	.42	.04	.12
3/15/67	.27	17.85	3.09	9.47	6.69	.25	.07	.07

* K-N - KJELDAHL-N
** p - Total Phosphates

STATISTISTICS OF LAND-USE CHARACTERISTIC/POLLUTANT LOAD ANALYSIS

Pollutant	Number of Observations*	COEFFICIENT A Functional Relationship	Correlation Coefficient	COEFFICIENT B Mean Value	Standard Deviation
T.S.S.	9	$I/(.1362 + .00384(I))$	0.99	1.05	0.27
B.O.D.	6	$7.3971-(83.0334/I)$	0.76	0.82	0.53
C.O.D.	8	$12.71\ e^{.0315(I)}$	0.72	0.86	0.19
KJELDAHL-N	5	$0.01369\ e^{.0888(I)}$	0.90	0.90	0.34
NH_3-N	4	$0.2437\ e^{.0438(I)}$	1.00	0.95	0.52
TOTAL PO_4	6	$0.01349\ e^{.09677(I)}$	0.94	0.89	0.42
D.O.	3	1.6**	1.00	1.09	——

Where: I is the percent of the basin which is impervious

* Number of study watersheds for which data was available.
** D.O. is a function of runoff volume only

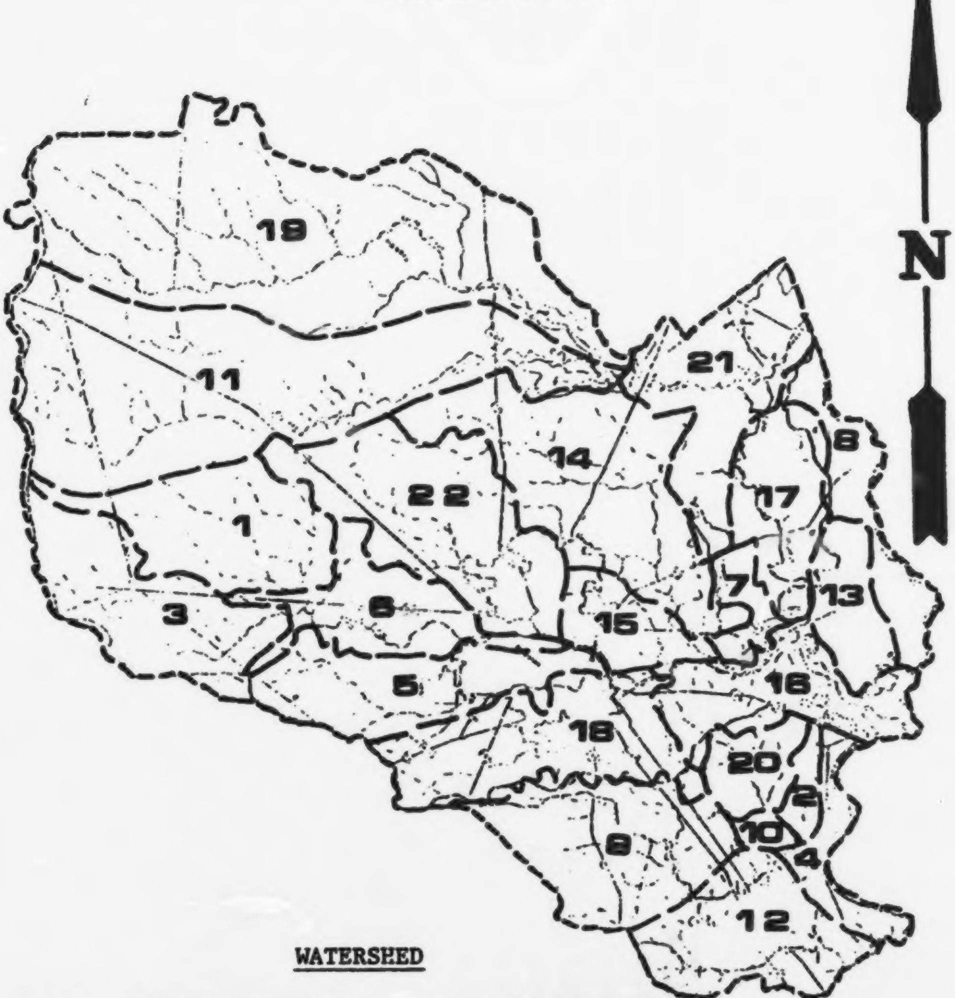
APPENDIX B

PEAK FLOWS AND CONCENTRATIONS AND TOTAL RUNOFF AND POLLUTANT LOADS FOR 208 AREA SUBCATCHMENTS AND BASINS

EXPLANATORY NOTE

The following tables are a summary of the data output from the urban stormwater analysis. Peak flows and concentrations and total runoff and pollutant loads for each major basin at the downstream node for three design storms for 1975 and the 2-year design storm for 1983, 1990, and 1995 are given. For basins not subject to analysis by the Storm Water Management Model, data is given for each subcatchment. See the Subcatchment Map (Exhibit I) and supplement for the location of each of these basins and subcatchments.

SUPPLEMENT TO
SUBCATCHMENT MAP



WATERSHED

1. ADDICKS RESERVOIR
2. TAYLOR BAYOU
3. BARKER RESERVOIR
4. BAYPORT AREA
5. BRAYS BAYOU
6. BUFFALO BAYOU
7. CARPENTERS BAYOU
8. CEDAR CREEK
9. CLEAR CREEK
10. CLEAR LAKE
11. CYPRESS CREEK
12. DICKINSON BAYOU
13. GOOSE CREEK
14. GREENS BAYOU
15. HUNTING BAYOU
16. LOWER SHIP CHANNEL
17. SAN JACINTO RIVER
18. SIMS BAYOU
19. SPRING CREEK
20. ARMAND BAYOU
21. LAKE HOUSTON
22. WHITE OAK BAYOU

CEDAR BAYOU

SUBCATCHMENT 2

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	150	26.6	37	680	.75	5.4	.75	.40	4.03	94.42	.077	1.116	.073
1975/6 month	320	51.5	45	1050	.80	7.7	.80	.45	6.85	189.04	.138	2.024	.137
1975/2 year	640	79.0	55	1150	.90	8.8	.90	.48	9.64	296.22	.202	2.975	.206
1983	690	79.0	61	1225	.90	8.9	.90	.52	9.64	296.22	.202	2.975	.206
1990	730	79.0	64	1275	.94	9.1	.95	.57	9.64	296.22	.202	2.975	.206
1995	770	79.0	67	1325	.98	9.3	.99	.60	9.64	296.22	.202	2.975	.206

CEDAR BAYOU

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	25.9	34	780	.75	5.2	.75	.40	3.94	70.83	.068	1.043	.065
1975/6 month	270	50.4	39	870	.80	7.5	.80	.45	6.71	142.36	.123	1.897	.123
1975/2 year	550	77.5	55	925	.90	8.5	.90	.48	9.45	223.39	.180	1.791	.185
1983	590	77.5	57	1200	.90	8.8	.90	.52	9.45	223.39	.180	1.791	.185
1990	640	77.5	59	1240	.95	9.1	.95	.57	9.45	223.39	.180	1.791	.185
1995	700	77.5	61	1280	.98	9.3	.98	.60	9.45	223.39	.180	1.791	.185

CARPENTERS BAYOU

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l) BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	234	30.7	59	1873	.90	4.0	.90	.402	7	314	.101	.777	.089
1975/6 month	481	63.2	83	2852	.94	5.0	.94	.233	14	701	.105	.971	.093
1975/2 year	822	108.0	103	3870	1.04	6.2	1.04	.163	21	1122	.116	1.204	.103
1983	957	125.7	101	3579	1.04	6.9	1.04	.140	21	1098	.116	1.340	.103
1990	1000	131.4	101	3644	1.09	7.3	1.09	.137	21	1110	.261	1.418	.232
1995	1053	138.3	100	3615	1.15	7.7	1.15	.131	37	1311	.435	1.496	.387

BUFFALO BAYOU

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	1033	199.0	117	2815	1.40	6.8	1.40	1.75	81	2266	.157	1.321	.138
1975/6 month	2193	422.5	167	4539	1.45	7.8	1.45	1.14	161	3654	.177	1.515	.155
1975/2 year	2552	491.7	211	6274	1.55	9.0	1.55	.925	255	5051	.216	1.748	.189
1983	2572	495.5	214	6443	1.56	9.7	1.56	.927	286	5187	.220	1.884	.192
1990	2751	530.0	217	6637	1.60	10.1	1.60	.928	296	5343	.236	1.962	.206
1995	2723	524.6	217	8772	1.64	10.7	1.64	.927	308	7062	.252	2.078	.220

BRAYS BAYOU

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	6154	1432.6	72	1649	1.60	7.8	1.60	.0746	235	1696	.179	1.515	.158
1975/6 month	11591	2326.6	80	2093	1.65	8.8	1.65	.0360	407	2153	.194	1.709	.171
1975/2 year	19065	2831.1	84	2406	1.75	10.0	1.75	.0213	593	2475	.224	1.942	.197
1983	22460	3193.9	83	2412	1.75	10.7	1.75	.0177	704	2481	.224	2.078	.197
1990	22342	3177.1	89	2631	1.79	11.6	1.79	.0233	767	2706	.236	2.253	.207
1995	23374	3214.9	91	2697	1.84	12.2	1.84	.0267	797	2774	.251	2.369	.220

BAYPORT

SUBCATCHMENT 2

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	105	20.5	32	620	.75	6.4	.75	.20	3.09	132.45	.087	1.023	.080
1975/6 month	250	39.2	40	900	.80	9.0	.80	.35	5.19	261.22	.155	1.831	.149
1975/2 year	475	59.8	46	1140	.90	12.5	.90	.40	7.27	407.02	.225	2.678	.222
1983	500	60.0	56	1170	.95	13.0	.95	.45	7.29	448.78	.249	2.804	.243
1990	520	60.0	59	1190	.97	13.8	.97	.50	7.29	448.78	.249	2.804	.243
1995	540	60.0	62	1220	.99	13.9	.99	.55	7.29	448.78	.249	2.804	.243

BAYPORT

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	95	23.2	30	600	.75	6.5	.75	.25	3.48	178.81	.119	1.259	.106
1975/6 month	230	43.9	38	875	.80	9.0	.80	.40	5.81	350.11	.210	2.239	.199
1975/2 year	450	66.8	44	1125	.90	12.0	.90	.50	8.13	544.01	.305	3.266	.297
1983	475	67.2	48	1150	.95	13.0	.95	.50	8.16	628.60	.372	3.582	.356
1990	500	67.3	56	1180	.95	13.5	.95	.60	8.26	668.68	.411	3.750	.390
1995	525	67.5	60	1200	1.0	13.8	1.0	.60	12.01	707.40	.454	3.927	.427

BARKER RESERVOIR

SUBCATCHMENT 11

			PEAK CONCENTRATIONS (mg/1)							TOTAL LOADS (TONS)			
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	9.5	84	780	.75	5.5	.75	.40	1.44	25.87	.025	.381	.024
1975/6 month	270	18.4	39	870	.80	7.8	.80	.45	2.45	52.00	.045	.693	.045
1975/2 year	550	28.3	60	925	.90	9.0	.90	.49	3.45	81.60	.066	1.020	.068
1983	590	28.3	63	1200	.90	9.1	.90	.52	3.45	81.60	.066	1.020	.068
1990	640	28.3	66	1240	.94	9.4	.94	.57	3.45	81.60	.066	1.020	.068
1995	700	28.3	69	1300	.97	9.9	.97	.59	3.45	81.60	.066	1.020	.068

BARKER RESERVOIR

SUBCATCHMENT 10

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
			BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	23.0	28	550	.75	5.4	.75	.25	3.49	81.71	.066	.966	.063
1975/6 month	175	44.6	37	780	.80	7.7	.80	.30	5.92	163.59	.120	1.752	.119
1975/2 year	360	68.4	45	1120	.90	8.8	.90	.36	8.34	256.34	.175	2.574	.178
1983	390	68.4	46	1125	.90	8.9	.90	.39	8.34	256.34	.175	2.574	.178
1990	410	68.6	47	1150	.93	9.1	.95	.42	8.36	313.34	.193	2.696	.195
1995	420	68.6	49	1210	.97	9.3	.98	.46	8.36	313.34	.193	2.696	.195

BARKER RESERVOIR

SUBCATCHMENT 9

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	60	17.7	23	520	.75	5.1	.75	.24	2.69	62.93	.051	.744	.049
1975/6 month	150	34.3	32	720	.80	7.2	.80	.28	4.56	125.99	.092	1.349	.092
1975/2 year	310	52.7	39	1040	.90	8.2	.90	.34	6.42	197.42	.135	1.982	.137
1983	340	52.8	40	1060	.90	8.4	.90	.35	6.44	241.32	.149	2.076	.151
1990	370	52.8	42	1070	.92	8.5	.93	.41	6.44	241.32	.149	2.076	.151
1995	390	52.9	44	1140	.94	8.7	.97	.42	6.45	283.35	.164	2.174	.165

BARKER RESERVOIR

SUBCATCHMENT 8

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	115	12.2	32	765	.75	5.5	.75	.19	1.85	33.20	.032	.489	.031
1975/6 month	165	23.6	37	855	.80	7.8	.80	.23	3.14	66.72	.058	.889	.058
1975/2 year	550	36.3	59	915	.90	9.0	.90	.31	4.43	104.70	.084	1.308	.087
1983	580	36.3	65	1195	.90	9.1	.90	.38	4.43	104.70	.084	1.308	.087
1990	640	36.3	67	1235	.95	9.4	.95	.40	4.43	104.70	.084	1.308	.087
1995	700	36.3	69	1310	.98	9.7	.98	.45	4.43	104.70	.084	1.308	.087

BARKER RESERVOIR

SUBCATCHMENT 7

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	13.5	28	550	.75	5.5	.75	.25	2.05	36.86	.035	.543	.034
1975/6 month	170	26.2	37	780	.80	7.8	.80	.30	3.49	74.08	.064	.987	.064
1975/2 year	350	40.3	45	1120	.90	9.0	.90	.34	4.92	116.24	.094	1.452	.096
1983	390	40.3	46	1125	.90	9.1	.90	.38	4.92	116.24	.094	1.452	.096
1990	410	40.3	47	1150	.94	9.2	.95	.42	4.92	116.24	.094	1.452	.096
1995	420	40.3	49	1210	.98	9.5	.98	.47	4.92	116.24	.094	1.452	.096

BARKER RESERVOIR

SUBCATCHMENT 6

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	18.6	34	780	.75	5.5	.75	.20	2.83	50.85	.049	.749	.047
1975/6 month	170	36.2	39	870	.80	7.8	.80	.25	4.81	102.19	.088	1.362	.058
1975/2 year	555	55.6	61	930	.90	9.0	.90	.34	6.78	160.36	.129	2.004	.133
1983	595	55.7	67	1210	.90	9.1	.90	.40	6.80	208.95	.143	2.098	.145
1990	645	55.9	69	1250	.95	9.4	.95	.44	6.81	255.42	.158	2.197	.159
1995	705	55.9	70	1325	.98	9.7	.98	.49	6.81	255.42	.158	2.197	.159

BARKER RESERVOIR

SUBCATCHMENT 5

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	100	5.2	31	760	.75	5.5	.75	.35	2.65	68.04	.077	.453	.064
1975/6 month	220	9.5	35	840	.80	7.8	.80	.40	4.29	128.36	.131	.781	.114
1975/2 year	500	14.3	55	880	.90	9.0	.90	.42	5.94	196.56	.188	1.125	.168
1983	550	14.5	58	1090	.90	9.1	.90	.46	7.75	237.35	.376	1.552	.318
1990	600	14.7	60	1180	.95	9.4	.95	.51	8.61	262.58	.617	1.953	.501
1995	670	14.8	63	1210	.98	9.7	.98	.54	9.03	276.47	.830	2.242	.658

BARKER RESERVOIR

SUBCATCHMENT 4

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	80	1.9	29	740	.75	5.5	.75	.30	.29	5.22	.005	.077	.005
1975/6 month	190	3.7	35	810	.80	7.8	.80	.37	.37	10.50	.009	.140	.009
1975/2 year	470	5.7	50	875	.90	9.0	.90	.40	.40	16.47	.013	.206	.014
1983	500	5.7	57	1100	.90	9.1	.90	.43	.43	16.47	.013	.206	.014
1990	530	5.7	60	1170	.95	9.4	.95	.46	.46	16.47	.013	.206	.014
1995	610	5.7	62	1190	.98	9.7	.98	.50	.50	16.47	.013	.206	.014

BARKER RESERVOIR

SUBCATCHMENT 3

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	141	21.7	34	766	.75	5.4	.75	.36	3.29	77.07	.063	.911	.060
1975/6 month	310	42.1	41	1120	.80	7.7	.80	.44	5.59	154.30	.113	1.652	.112
1975/2 year	620	64.5	63	1210	.90	9.1	.90	.46	7.87	241.78	.165	2.428	.168
1983	690	64.5	68	1260	.90	9.2	.90	.49	7.87	241.78	.165	2.428	.168
1990	720	64.5	73	1310	.95	9.4	.95	.56	7.87	241.78	.165	2.428	.168
1995	755	64.5	76	1350	.98	9.7	.98	.62	7.87	241.78	.165	2.428	.168

BARKER RESERVOIR

SUBCATCHMENT 2

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	140	36.6	34	765	.75	5.5	.75	.36	5.55	99.83	.096	1.470	.092
1975/6 month	300	71.1	41	1100	.80	7.8	.80	.42	9.45	200.63	.173	2.674	.173
1975/2 year	600	109.2	61	1200	.90	9.0	.90	.45	13.32	314.82	.254	3.934	.261
1983	660	109.2	65	1250	.90	9.1	.90	.48	13.32	314.82	.254	3.934	.261
1990	700	109.2	68	1290	.95	9.4	.95	.54	13.32	314.82	.254	3.934	.261
1995	750	109.2	70	1340	.98	9.7	.98	.59	13.32	314.82	.254	3.934	.261

BARKER RESERVOIR

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	110	6.0	31	765	.75	5.5	.75	.35	.91	16.29	.016	.240	.015
1975/6 month	230	11.6	37	850	.80	7.8	.80	.40	1.54	32.73	.028	.436	.028
1975/2 year	510	17.8	57	900	.90	9.0	.90	.43	2.17	51.36	.041	.642	.043
1983	560	17.8	61	1180	.90	9.1	.90	.47	2.17	51.36	.041	.642	.043
1990	610	17.8	64	1200	.95	9.4	.95	.52	2.17	51.36	.041	.642	.043
1995	680	17.8	66	1290	.98	9.7	.98	.55	2.17	51.36	.041	.642	.043

ARMAND BAYOU

SUBCATCHMENT 9

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	150	12.4	35	770	.75	3.7	.75	.20	1.87	88.27	.058	.647	.053
1975/6 month	300	23.6	40	860	.80	4.2	.80	.25	3.13	173.46	.103	1.154	.098
1975/2 year	600	36.0	62	910	.90	5.2	.90	.32	4.38	269.91	.149	1.686	.146
1983	640	37.2	68	1180	.90	6.3	.90	.40	4.40	317.35	.182	1.849	.176
1990	670	36.3	69	1220	.95	6.9	.95	.43	4.41	339.80	.201	1.936	.192
1995	690	36.4	71	1275	.99	7.1	.97	.47	4.46	361.46	.222	2.027	.211

ARMAND BAYOU

SUBCATCHMENT 8

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	27.7	34	780	.75	3.5	.75	.20	9.13	303.39	.253	1.952	.221
1975/6 month	170	51.6	39	870	.80	4.5	.80	.25	14.99	581.79	.440	3.411	.398
1975/2 year	550	77.9	60	925	.90	5.7	.90	.32	20.84	896.73	.635	4.943	.589
1983	590	78.6	64	1200	.90	6.4	.90	.38	30.88	1050.86	.943	5.942	.847
1990	640	79.2	67	1240	.95	6.8	.95	.42	36.24	1155.31	1.269	6.820	1.114
1995	700	80.4	68	1310	.97	7.3	.98	.47	43.90	1341.32	2.297	8.986	1.924

ARMAND BAYOU

SUBCATCHMENT 7

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	6.0	28	550	.75	5.5	.75	.25	.91	42.92	.028	.315	.026
1975/6 month	170	11.5	37	780	.80	7.8	.80	.30	1.52	84.34	.050	.561	.048
1975/2 year	350	17.5	45	1120	.90	9.0	.90	.34	2.13	131.23	.073	.820	.071
1983	390	17.6	46	1125	.90	9.1	.90	.38	2.14	142.98	.080	.859	.078
1990	410	17.6	47	1150	.94	9.2	.95	.42	2.14	154.30	.089	.899	.085
1995	420	17.6	49	1210	.98	9.5	.98	.47	2.14	154.30	.089	.899	.085

ARMAND BAYOU

SUBCATCHMENT 6

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	50	2.8	20	490	.75	5.1	.75	.20	.43	7.68	.007	.113	.007
1975/6 month	110	5.5	24	610	.80	7.4	.80	.25	.73	15.43	.013	.206	.013
1975/2 year	210	8.4	28	850	.90	8.5	.90	.30	1.02	24.21	.020	.303	.020
1983	225	8.4	32	870	.90	8.6	.90	.35	1.03	31.55	.022	.317	.022
1990	240	8.4	34	890	.92	8.8	.92	.40	1.03	31.55	.022	.317	.022
1995	265	8.5	38	910	.94	9.0	.94	.45	1.03	45.28	.026	.347	.026

ARMAND BAYOU

SUBCATCHMENT 5

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	14.2	34	780	.75	5.5	.75	.40	2.15	82.19	.055	.679	.051
1975/6 month	270	27.2	39	870	.80	7.8	.80	.45	3.61	162.69	.098	1.219	[illegible]
1975/2 year	550	41.6	60	925	.90	9.0	.90	.49	5.07	253.84	.142	1.785	[illegible]
1983	590	41.8	63	1200	.90	9.1	.90	.52	5.09	313.35	.174	1.958	.170
1990	640	41.9	66	1240	.94	9.4	.94	.57	5.10	341.40	.192	2.050	.186
1995	700	42.0	69	1300	.97	9.9	.97	.59	5.11	368.43	.212	2.146	.204

ARMAND BAYOU

SUBCATCHMENT 4

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	140	9.6	35	770	.75	3.7	.75	.20	1.46	34.09	.028	.403	.026
1975/6 month	280	18.6	41	860	.80	4.3	.80	.24	2.47	68.26	.050	.731	.050
1975/2 year	570	28.5	58	910	.90	5.1	.90	.29	3.48	106.95	.073	1.074	.074
1983	620	28.5	59	1180	.90	6.1	.90	.33	3.48	106.95	.073	1.074	.074
1990	640	28.5	60	1230	.94	6.7	.95	.37	3.48	106.95	.073	1.074	.074
1995	670	28.5	62	1260	.98	7.0	.97	.41	3.48	106.95	.073	1.074	.074

ARMAND BAYOU

SUBCATCHMENT 3

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	50	6.1	22	470	.75	5.2	.75	.18	.92	26.40	.019	.267	.018
1975/6 month	120	11.8	31	580	.80	7.8	.80	.22	1.56	52.65	.035	.483	.034
1975/2 year	270	18.0	39	870	.90	8.2	.90	.27	2.20	82.39	.051	.709	.051
1983	290	18.2	40	920	.90	8.5	.90	.34	2.21	123.70	.068	.814	.068
1990	315	18.2	42	940	.95	8.7	.95	.39	2.22	148.61	.083	.892	.081
1995	340	18.3	43	980	.97	8.9	.97	.42	2.23	171.72	.102	.978	.097

ARMAND BAYOU

SUBCATCHMENT 2

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	40	3.6	21	450	.75	3.5	.75	.20	1.36	41.58	.037	.268	.032
1975/6 month	75	6.7	24	525	.80	4.6	.80	.25	2.23	79.47	.063	.467	.057
1975/2 year	120	10.2	33	580	.90	5.8	.90	.28	3.10	122.32	.091	.676	.084
1983	140	10.3	38	640	.90	6.5	.90	.32	4.73	150.82	.166	.890	.145
1990	170	10.4	39	690	.95	6.9	.95	.35	5.11	159.32	.202	.976	.174
1995	195	10.4	41	720	.97	7.3	.97	.39	5.44	167.40	.246	1.070	.209

ARMAND BAYOU

SUBCATCHMENT 1

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	25	10.1	15	450	.75	3.5	.75	.20	2.80	105.47	.084	.680	.074
1975/6 month	50	18.8	22	470	.80	4.5	.80	.24	4.62	202.94	.146	1.192	.133
1975/2 year	85	28.4	25	550	.90	5.7	.90	.28	6.42	313.21	.211	1.729	.197
1983	115	28.7	30	620	.90	6.4	.90	.32	9.67	357.53	.283	1.985	.259
1990	135	28.8	34	640	.95	6.8	.95	.35	11.31	384.91	.345	2.176	.310
1995	150	28.9	39	650	.97	7.2	.98	.39	12.68	410.76	.421	2.386	.372

ADDICKS RESERVOIR

SUBCATCHMENT 9

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	60	10.5	23	520	.75	5.1	.75	.24	1.70	28.29	.029	.437	.027
1975/6 month	150	24.2	32	720	.80	7.2	.80	.28	3.31	67.72	.060	.923	.059
1975/2 year	310	39.2	39	1040	.90	8.2	.90	.34	4.88	112.60	.092	1.427	.094
1983	340	39.2	40	1060	.90	8.4	.90	.35	4.88	112.60	.092	1.427	.094
1990	370	39.2	42	1070	.92	8.5	.92	.41	4.88	112.60	.092	1.427	.094
1995	390	39.2	44	1140	.94	8.7	.94	.42	4.88	112.60	.092	1.427	.094

ADDICKS RESERVOIR

SUBCATCHMENT 8

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	50	0.9	20	490	.75	5.1	.75	.20	.14	2.40	.002	.037	.002
1975/6 month	110	2.1	24	610	.80	7.4	.80	.25	.28	5.75	.005	.078	.005
1975/2 year	210	3.3	28	850	.90	8.5	.90	.30	.41	9.55	.008	.121	.008
1983	225	3.3	32	870	.90	8.6	.90	.34	.41	9.55	.008	.121	.008
1990	240	3.3	34	890	.92	8.8	.92	.38	.41	9.55	.008	.121	.008
1995	265	3.3	38	910	.94	9.0	.94	.42	.41	9.55	.008	.121	.008

ADDICKS RESERVOIR

SUBCATCHMENT 7

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	4.9	34	780	.75	5.5	.75	.40	.80	13.21	.013	.204	.013
1975/6 month	250	11.3	38	850	.80	7.5	.80	.44	1.55	31.62	.028	.431	.028
1975/2 year	530	18.3	54	910	.90	8.8	.90	.49	2.28	52.58	.043	.666	.044
1983	570	18.3	59	1160	.90	8.9	.90	.53	2.28	52.58	.043	.666	.044
1990	610	18.3	63	1220	.94	9.2	.94	.57	2.28	52.58	.043	.666	.044
1995	680	18.3	66	1280	.98	9.7	.98	.61	2.28	52.58	.043	.666	.044

ADDICKS RESERVOIR

SUBCATCHMENT 6

			PEAK CONCENTRATIONS (mg/1)							TOTAL LOADS (TONS)		
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	28.8	35	620	.75	6.5	.75	.30	4.64	100.53	.086	1.245	.080
1975/6 month	270	65.5	39	900	.80	9.0	.80	.36	8.97	238.65	.179	2.613	.176
1975/2 year	540	106.1	49	1140	.90	10.8	.90	.42	13.19	395.83	.274	4.031	.278
1983	575	106.5	63	1180	.90	11.5	.90	.47	13.23	484.50	.303	4.226	.305
1990	590	106.5	68	1240	.94	12.2	.94	.54	13.23	484.50	.303	4.226	.305
1995	620	106.5	72	1280	.99	12.9	.99	.58	13.23	484.50	.303	4.226	.305

ADDICKS RESERVOIR

SUBCATCHMENT 5

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	225	54.2	38	900	.75	9.0	.75	.35	8.77	145.69	.147	2.250	.139
1975/6 month	300	124.5	42	1050	.80	12.4	.80	.42	17.06	348.78	.308	4.754	.306
1975/2 year	600	202.1	47	1140	.90	12.9	.90	.47	25.13	579.94	.475	7.351	.485
1983	650	202.8	51	1180	.90	13.2	.90	.52	25.21	756.69	.525	7.707	.532
1990	680	202.8	56	1240	.94	13.7	.94	.55	25.21	756.69	.525	7.707	.532
1995	710	202.1	59	1300	.95	14.1	.98	.59	25.13	579.94	.475	7.351	.485

ADDICKS RESERVOIR

SUBCATCHMENT 4

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	19.3	35	620	.75	6.5	.75	.30	3.10	82.16	.063	.870	.059
1975/6 month	270	43.6	39	900	.80	9.0	.80	.35	5.95	193.46	.131	1.814	.128
1975/2 year	540	70.4	49	1210	.90	12.4	.90	.39	8.74	320.09	.200	2.792	.202
1983	575	70.4	63	1240	.95	12.6	.95	.44	8.74	320.09	.200	2.792	.202
1990	590	70.1	68	1260	.97	12.9	.97	.47	8.71	261.51	.181	2.663	.184
1995	620	70.1	72	1280	.99	13.6	.99	.49	8.71	126.51	.181	2.663	.184

ADDICKS RESERVOIR

SUBCATCHMENT 3

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	4.3	28	540	.75	5.4	.75	.25	.69	11.45	.012	.177	.011
1975/6 month	175	9.8	37	770	.80	7.6	.80	.30	1.34	27.41	.024	.374	.024
1975/2 year	360	15.9	44	1050	.90	8.6	.90	.34	1.97	45.58	.037	.578	.038
1983	390	15.9	45	1080	.90	8.8	.90	.41	1.98	59.47	.041	.606	.042
1990	410	15.9	46	1100	.93	8.9	.93	.45	1.98	59.47	.041	.606	.042
1995	420	16.0	48	1125	.97	9.2	.97	.50	1.99	72.79	.046	.635	.046

ADDICKS RESERVOIR

SUBCATCHMENT 2

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	7.9	28	550	.75	5.5	.75	.25	1.28	21.20	.021	.327	.020
1975/6 month	175	18.1	37	780	.80	7.8	.80	.30	2.48	50.75	.045	.692	.045
1975/2 year	360	29.4	45	1120	.90	8.8	.90	.34	3.66	84.38	.069	1.070	.071
1983	390	29.4	46	1125	.90	8.9	.90	.38	3.66	84.38	.069	1.070	.071
1990	410	29.4	47	1150	.95	9.1	.95	.42	3.66	84.38	.069	1.070	.071
1995	420	29.4	49	1210	.98	9.4	.98	.47	3.66	84.38	.069	1.070	.071

ADDICKS RESERVOIR

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	125	9.7	35	600	.75	6.4	.75	.30	1.58	26.17	.026	.404	.025
1975/6 month	275	22.4	38	900	.80	8.8	.80	.35	3.06	62.64	.055	.854	.055
1975/2 year	565	36.3	47	1190	.90	12.2	.90	.40	4.51	104.16	.085	1.320	.067
1983	590	36.3	62	1230	.90	12.6	.90	.45	4.51	104.16	.085	1.320	.087
1990	610	36.3	65	1250	.95	13.1	.95	.48	4.51	104.16	.085	1.320	.087
1995	640	36.3	73	1275	.99	14.3	.99	.52	4.51	104.16	.085	1.320	.067

CEDAR BAYOU

SUBCATCHMENT 3

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	38.2	35	600	.75	6.4	.75	.30	5.79	165.45	.121	1.675	.115
1975/6 month	270	73.8	39	870	.80	8.7	.80	.34	9.79	329.97	.216	3.026	.215
1975/2 year	540	113.0	49	1180	.90	12.0	.90	.40	13.77	516.31	.319	4.442	.322
1983	575	113.3	63	1210	.90	12.6	.90	.45	13.80	606.24	.352	4.651	.353
1990	590	113.3	67	1240	.94	13.1	.94	.48	13.80	606.24	.352	4.651	.353
1995	620	113.6	71	1260	.97	13.7	.97	.52	13.83	692.46	.388	4.870	.386

CEDAR BAYOU

SUBCATCHMENT 4

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	23.7	28	550	.75	5.2	.75	.25	3.57	183.34	.122	1.291	.111
1975/6 month	175	45.0	37	780	.80	7.1	.80	.30	5.96	358.99	.215	2.296	.204
1975/2 year	360	68.5	45	1115	.90	8.4	.90	.36	8.33	557.81	.313	3.349	.304
1983	390	69.0	46	1130	.90	8.8	.90	.39	8.46	685.63	.421	3.845	.400
1990	410	69.2	47	1140	.94	8.9	.94	.42	12.31	725.34	.465	4.026	.438
1995	420	69.2	49	1170	.98	9.1	.97	.46	12.31	725.34	.465	4.026	.433

NONTIDAL PORTION

CLEAR CREEK

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	760	146.4	18	796	1.39	6.8	1.39	.00270	25	798	.156	1.314	.137
1975/6 month	1540	289.7	26	1218	1.44	7.8	1.44	.00180	54	1880	.176	1.507	.154
1975/2 year	2616	504.0	33	1656	1.54	8.9	1.54	.00130	78	2992	.215	1.739	.188
1983	2745	528.8	34	2420	1.55	9.6	1.55	.01660	95	4372	.219	1.874	.191
1990	2959	570.1	74	3040	1.59	10.0	1.59	.03020	158	5492	.235	1.952	.205
1995	3171	610.9	114	3541	1.63	10.6	1.63	.03920	231	6397	.251	2.068	.219

TIDAL PORTION

CLEAR CREEK

SUBCATCHMENT 10

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	15.3	28	550	.75	5.5	.75	.25	2.33	54.51	.044	.644	.042
1975/6 month	175	29.7	37	780	.80	7.8	.80	.30	3.95	109.13	.080	1.169	.079
1975/2 year	360	45.6	45	1120	.90	9.0	.90	.34	5.56	171.00	.117	1.717	.119
1983	390	45.6	46	1125	.90	9.1	.90	.38	5.56	171.00	.117	1.717	.119
1990	410	45.7	47	1150	.95	9.2	.95	.42	5.58	209.03	.129	1.798	.130
1995	420	45.7	49	1210	.98	9.5	.98	.47	5.58	209.03	.129	1.798	.130

TIDAL PORTION
CLEAR CREEK
SUBCATCHMENT 11

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	70	12.7	24	520	.75	5.2	.75	.20	1.92	44.96	.037	.532	.035
1975/6 month	150	24.5	32	720	.80	7.6	.80	.25	3.26	90.02	.066	.964	.065
1975/2 year	320	37.6	39	1050	.90	8.7	.90	.29	4.59	141.05	.096	1.416	.095
1983	370	37.6	42	1075	.90	9.0	.90	.30	4.59	141.05	.096	1.416	.096
1990	390	37.6	43	1125	.92	9.1	.92	.35	4.59	141.05	.096	1.416	.098
1995	415	37.6	44	1200	.97	9.3	.97	.38	4.59	141.05	.096	1.416	.098

TIDAL PORTION

CLEAR CREEK

SUBCATCHMENT 12

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	50	5.5	20	490	.75	5.1	.75	.20	.83	27.76	.019	.250	.018
1975/6 month	110	10.5	24	610	.80	7.4	.80	.25	1.40	55.16	.034	.415	.033
1975/2 year	210	16.1	28	850	.90	8.5	.90	.30	1.96	86.18	.050	.661	.050
1983	225	16.2	32	870	.90	8.6	.90	.35	1.97	110.20	.061	.725	.063
1990	240	16.3	34	890	.92	8.8	.92	.40	1.98	132.39	.074	.795	.072
1995	265	16.3	38	910	.94	9.0	.94	.45	1.98	142.87	.082	.832	.079

TIDAL PORTION

CLEAR CREEK

SUBCATCHMENT 13

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	25	1.4	15	450	.75	3.5	.75	.20	.21	3.78	.004	.056	.003
1975/6 month	50	2.7	22	470	.80	4.5	.80	.24	.36	7.60	.007	.101	.007
1975/2 year	85	4.1	25	550	.90	5.7	.90	.28	.50	11.92	.010	.149	.010
1983	115	4.1	30	620	.90	6.4	.90	.32	.50	11.92	.010	.149	.010
1990	130	4.1	34	640	.95	6.8	.95	.35	.50	11.92	.010	.149	.010
1995	145	4.1	39	650	.97	7.2	.98	.37	.50	11.92	.010	.149	.010

TIDAL PORTION

CLEAR CREEK

SUBCATCHMENT 14

					PEAK CONCENTRATIONS (mg/1)				TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	50	6.9	20	480	.75	5.0	.75	.18	1.04	18.78	.018	.277	.017
1975/6 month	110	13.4	24	590	.80	7.2	.80	.23	1.78	37.75	.033	.503	.033
1975/2 year	210	20.5	27	830	.90	8.3	.90	.30	2.51	59.23	.048	.740	.049
1983	225	20.5	31	880	.90	8.4	.90	.36	2.51	59.23	.048	.740	.049
1990	240	20.5	33	895	.92	8.5	.92	.42	2.51	59.23	.048	.740	.049
1995	265	20.5	36	925	.94	8.8	.94	.44	2.51	59.23	.048	.740	.049

TIDAL PORTION

CLEAR CREEK

SUBCATCHMENT 15

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	125	29.1	35	600	.75	6.4	.75	.30	4.37	224.54	.149	1.580	.136
1975/6 month	275	55.2	38	900	.80	8.8	.80	.35	7.29	439.64	.264	2.811	.250
1975/2 year	565	83.9	47	1190	.90	12.2	.90	.40	10.20	683.13	.383	4.102	.373
1983	590	83.9	62	1230	.95	12.6	.95	.45	10.20	683.13	.383	4.102	.373
1990	610	83.9	65	1250	.99	13.1	.97	.48	10.20	683.13	.383	4.102	.373
1995	640	83.9	73	1275	1.05	14.3	1.05	.52	10.20	683.13	.383	4.102	.373

CLEAR LAKE

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	25	6.5	15	450	.75	3.5	.75	.20	.98	50.37	.033	.355	.031
1975/6 month	50	12.4	22	470	.80	4.5	.80	.24	1.64	98.62	.059	.631	.056
1975/2 year	85	18.8	25	550	.90	5.7	.90	.27	2.29	153.24	.086	.920	.084
1983	115	18.8	30	620	.90	6.4	.90	.31	2.29	153.24	.086	.920	.084
1990	130	18.8	34	640	.94	6.8	.94	.33	2.29	153.24	.086	.920	.084
1995	145	18.8	39	650	.97	7.2	.97	.36	2.29	153.24	.086	.920	.084

CYPRESS CREEK

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	237	31.1	27	757	1.15	5.3	1.15	.0807	8	158	.129	1.030	.113
1975/6 month	806	105.9	37	1123	1.20	6.3	1.20	.0587	11	471	.172	1.224	.151
1975/2 year	1712	224.9	44	1458	1.30	7.1	1.30	.0255	36	854	.258	1.379	.226
1983	1728	227.0	40	1336	1.32	7.8	1.32	.0235	35	840	.275	1.515	.241
1990	1743	228.9	38	1303	1.37	8.3	1.37	.0220	33	840	.318	1.612	.279
1995	1750	229.9	37	1278	1.41	8.9	1.41	.0214	32	837	.352	1.728	.309

DICKINSON BAYOU

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	50.8	34	780	.75	5.5	.75	.40	7.71	180.43	.147	2.133	.140
1975/6 month	270	98.5	39	870	.80	7.8	.80	.45	13.08	361.23	.264	3.868	.262
1975/2 year	550	151.0	60	925	.90	9.0	.90	.48	18.42	566.02	.387	5.684	.394
1983	590	151.0	64	1200	.90	9.1	.90	.52	18.42	566.02	.387	5.684	.394
1990	640	151.4	67	1240	.95	9.4	.95	.57	18.45	691.88	.427	5.952	.432
1995	700	151.4	68	1300	.98	9.7	.98	.60	18.45	691.88	.427	5.952	.432

DICKINSON BAYOU

SUBCATCHMENT 2

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	150	66.9	37	780	.75	5.7	.75	.40	10.12	339.33	.234	3.061	.220
1975/6 month	320	128.7	45	1120	.80	8.1	.80	.45	17.07	674.23	.419	5.513	.409
1975/2 year	640	196.8	64	1250	.90	9.1	.90	.48	23.98	1053.48	.611	8.082	.613
1983	690	197.3	68	1275	.90	9.4	.90	.52	24.03	1203.31	.675	8.463	.672
1990	730	197.3	71	1325	.95	9.5	.95	.57	24.03	1203.31	.675	8.463	.672
1995	770	197.3	72	1350	.99	9.7	.99	.60	24.03	1203.31	.675	8.463	.672

DICKINSON BAYOU

SUBCATCHMENT 3

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	80	27.7	28	550	.75	5.4	.75	.25	9.13	303.39	.253	1.952	.221
1975/6 month	170	51.6	37	780	.80	7.7	.80	.30	14.99	581.79	.440	3.411	.398
1975/2 year	350	77.9	45	1120	.90	9.1	.90	.34	20.84	896.73	.635	4.943	.589
1983	380	78.6	46	1125	.90	9.2	.90	.38	30.88	1050.86	.943	5.942	.847
1990	400	79.2	47	1150	.95	9.4	.95	.41	36.24	1155.31	1.269	6.820	1.114
1995	425	80.4	49	1210	.98	9.7	.98	.45	43.90	1341.32	2.297	8.986	1.924

GOOSE CREEK

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	25	10.6	15	450	.75	3.4	.75	.20	1.61	37.72	.031	.446	.029
1975/6 month	50	20.6	22	470	.80	4.4	.80	.23	2.73	75.52	.055	.609	.055
1975/2 year	85	31.6	25	550	.90	5.5	.90	.27	3.85	118.34	.081	1.188	.082
1983	115	31.6	30	620	.90	6.2	.90	.30	3.85	118.34	.081	1.188	.082
1990	135	31.6	34	640	.93	6.7	.93	.34	3.85	118.34	.081	1.188	.082
1995	150	31.6	39	650	.96	6.9	.96	.38	3.86	144.65	.089	1.244	.090

GOOSE CREEK

SUBCATCHMENT 2

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	28.2	28	550	.75	5.4	.75	.25	14.36	369.34	.416	2.461	.349
1975/6 month	175	51.6	37	780	.80	7.7	.80	.30	23.30	696.76	.712	4.239	.620
1975/2 year	360	77.4	45	1120	.90	8.8	.90	.36	32.23	1066.97	1.022	6.109	.911
1983	390	78.0	46	1125	.90	8.9	.90	.39	37.07	1166.77	1.375	7.012	1.198
1990	410	78.0	47	1150	.93	9.1	.95	.42	37.07	1166.77	1.375	7.012	1.198
1995	420	78.2	49	1210	.97	9.3	.98	.46	38.45	1198.33	1.519	7.342	1.312

GREENS BAYOU

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	1530	254.3	103	2119	1.50	7.0	1.50	.289	96	3279	.168	1.360	.148
1975/6 month	3333	554.1	110	2606	1.55	8.0	1.55	.0811	177	4033	.185	1.554	.163
1975/2 year	5646	938.6	108	2805	1.65	9.2	1.65	.0197	254	4341	.219	1.787	.193
1983	6233	1036.2	114	2922	1.66	9.9	1.66	.0190	370	4522	.222	1.923	.196
1990	6374	1059.6	109	2830	1.70	10.3	1.70	.0187	415	4380	.235	2.001	.208
1995	6753	1122.6	114	2952	1.74	10.7	1.74	.0168	401	4569	.248	2.079	.220

HUNTING BAYOU

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	1641	272.4	30	723	1.40	6.5	1.40	.027	51	1203	.157	1.263	.138
1975/6 month	3287	545.7	33	900	1.45	7.5	1.45	.0836	89	2371	.177	1.457	.155
1975/2 year	5461	906.6	46	1273	1.55	8.8	1.55	.0263	131	3859	.216	1.709	.189
1983	4689	778.4	168	4797	1.55	9.3	1.55	.479	137	4006	.216	1.806	.189
1990	4836	802.8	175	5138	1.65	9.6	1.65	.514	147	4313	.255	1.864	.223
1995	5089	844.8	176	5145	1.68	10.0	1.68	.512	152	4442	.266	1.942	.233

LAKE HOUSTON

SUBCATCHMENT 1

			PEAK CONCENTRATIONS (mg/l)							TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	25	9.2	15	460	.75	3.3	.75	.20	1.49	32.23	.028	.399	.026
1975/6 month	50	21.0	21	480	.80	3.5	.80	.23	2.88	76.52	.057	.838	.056
1975/2 year	85	34.0	26	560	.90	5.5	.90	.27	4.23	126.91	.088	1.293	.089
1983	120	34.0	31	630	.90	6.2	.90	.30	4.23	126.91	.088	1.293	.089
1990	140	34.1	35	650	.93	6.7	.93	.34	4.24	155.34	.097	1.355	.098
1995	160	34.1	40	660	.96	7.1	.96	.38	4.24	155.34	.097	1.355	.098

LAKE HOUSTON

SUBCATCHMENT 2

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	80	21.1	27	550	.75	5.4	.75	.25	3.39	105.64	.076	.996	.071
1975/6 month	175	47.4	36	770	.80	7.7	.80	.30	6.47	246.74	.157	2.062	.152
1975/2 year	350	76.4	44	1110	.90	8.8	.90	.36	9.48	407.23	.240	3.167	.239
1983	390	76.7	46	1120	.90	8.9	.90	.39	9.51	465.76	.265	3.321	.262
1990	410	76.7	47	1140	.93	9.1	.95	.42	9.51	465.76	.265	3.321	.262
1995	430	76.7	48	1210	.97	9.3	.98	.46	9.51	465.76	.265	3.321	.262

LAKE HOUSTON

SUBCATCHMENT 3

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	70	11.8	24	530	.75	5.2	.75	.24	1.89	67.21	.047	.580	.043
1975/6 month	160	26.3	33	740	.80	7.5	.80	.28	3.58	155.74	.096	1.192	.092
1975/2 year	330	42.2	41	1060	.90	8.4	.90	.34	5.24	256.42	.146	1.828	.144
1983	370	42.6	42	1080	.90	8.7	.90	.35	5.27	317.35	.178	2.009	.174
1990	390	42.7	44	1095	.93	8.8	.93	.41	5.28	346.22	.197	2.106	.190
1995	410	42.9	46	1200	.97	8.9	.97	.42	5.30	374.10	.218	2.208	.209

LAKE HOUSTON

SUBCATCHMENT 4

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	60	15.1	23	520	.75	5.1	.75	.24	2.44	52.75	.045	.653	.042
1975/6 month	150	34.4	32	720	.80	7.2	.80	.28	4.71	125.23	.094	1.371	.092
1975/2 year	310	55.7	39	1040	.90	8.2	.90	.34	6.92	207.71	.144	2.115	.146
1983	340	55.9	40	1060	.90	8.4	.90	.35	6.94	254.23	.159	2.218	.160
1990	370	55.9	42	1070	.92	8.5	.93	.41	6.94	254.23	.159	2.218	.160
1995	390	55.9	44	1140	.94	8.7	.97	.42	6.94	254.23	.159	2.218	.160

LAKE HOUSTON

SUBCATCHMENT 5

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	2.7	28	540	.75	5.4	.75	.25	.43	9.39	.008	.116	.008
1975/6 month	175	6.1	37	770	.80	7.8	.80	.30	.84	22.30	.017	.244	.016
1975/2 year	360	9.9	45	1090	.90	9.0	.90	.34	1.23	36.99	.026	.377	.026
1983	390	9.9	46	1100	.90	9.2	.90	.41	1.23	36.99	.026	.377	.026
1990	410	9.9	47	1150	.93	9.3	.94	.45	1.24	45.27	.028	.395	.028
1995	430	9.9	49	1200	.97	9.5	.97	.50	1.24	45.27	.028	.395	.028

LAKE HOUSTON

SUBCATCHMENT 6

			PEAK CONCENTRATIONS (mg/1)							TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	3.9	34	780	.75	5.5	.75	.40	.64	10.59	.011	.163	.010
1975/6 month	270	9.0	39	870	.80	7.8	.80	.44	1.24	25.34	.022	.345	.022
1975/2 year	550	14.7	60	925	.90	9.0	.90	.48	1.83	42.14	.034	.534	.035
1983	590	14.7	63	1200	.90	9.1	.90	.52	1.83	42.14	.034	.534	.035
1990	640	14.7	66	1240	.94	9.4	.94	.55	1.83	42.14	.034	.534	.035
1995	700	14.7	69	1300	.97	9.9	.97	.59	1.83	42.14	.034	.534	.035

LAKE HOUSTON

SUBCATCHMENT 7

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	27.9	35	600	.75	6.4	.75	.30	4.51	79.92	.076	1.157	.071
1975/6 month	270	64.0	39	870	.80	8.7	.80	.34	8.77	179.37	.159	2.445	.157
1975/2 year	540	103.9	49	1180	.90	12.0	.90	.40	12.92	298.24	.244	3.780	.249
1983	575	103.9	63	1210	.90	12.6	.90	.45	12.92	298.24	.244	3.780	.249
1990	590	103.9	67	1240	.94	13.1	.94	.48	12.92	298.24	.244	3.780	.249
1995	620	103.9	71	1260	.97	13.7	.97	.52	12.92	298.24	.244	3.780	.249

LAKE HOUSTON

SUBCATCHMENT 8

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	14.6	28	550	.75	5.2	.75	.25	2.37	39.32	.040	.607	.037
1975/6 month	170	33.6	36	780	.80	7.1	.80	.30	4.60	94.13	.083	1.283	.083
1975/2 year	350	54.5	44	1115	.90	8.4	.90	.36	6.78	156.51	.128	1.984	.131
1983	390	54.5	47	1130	.90	8.8	.90	.39	6.78	156.51	.128	1.984	.131
1990	410	54.5	48	1140	.94	8.9	.94	.44	6.78	156.51	.128	1.984	.131
1995	425	54.5	52	1170	.98	9.1	.97	.47	6.78	156.51	.128	1.984	.131

LAKE HOUSTON

SUBCATCHMENT 9

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	5.7	34	780	.75	5.5	.75	.40	.92	32.72	.023	.282	.021
1975/6 month	270	12.8	39	870	.80	7.8	.80	.44	1.74	75.83	.047	.581	.045
1975/2 year	550	20.6	60	925	.85	9.0	.80	.48	2.55	124.85	.071	.890	.070
1983	590	20.6	63	1200	.90	9.1	.90	.52	2.56	139.96	.079	.933	.077
1990	640	20.6	66	1240	.94	9.4	.94	.55	2.56	139.96	.079	.933	.077
1995	700	20.6	69	1300	.97	9.7	.97	.59	2.56	139.96	.079	.933	.077

LAKE HOUSTON

SUBCATCHMENT 10

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	7.7	28	540	.75	5.4	.75	.25	1.24	26.86	.023	.333	.021
1975/6 month	175	17.5	37	760	.80	7.8	.80	.30	2.40	63.76	.048	.698	.047
1975/2 year	360	28.3	45	1090	.90	9.0	.90	.34	3.52	105.75	.073	1.077	.074
1983	390	28.4	46	1100	.90	9.2	.90	.41	3.53	129.43	.081	1.129	.081
1990	410	28.6	47	1150	.94	9.4	.94	.45	3.54	152.18	.090	1.184	.089
1995	430	28.6	49	1200	.98	9.6	.98	.50	3.54	152.18	.090	1.184	.089

LAKE HOUSTON

SUBCATCHMENT 11

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	16.9	28	550	.75	5.5	.75	.25	2.73	59.16	.051	.733	.047
1975/6 month	175	38.6	37	780	.80	7.8	.80	.30	5.28	140.44	.105	1.538	.104
1975/2 year	360	62.4	45	1100	.90	9.0	.90	.34	7.76	232.93	.162	2.372	.164
1983	390	62.4	46	1110	.90	9.2	.90	.38	7.76	232.93	.162	2.372	.164
1990	410	62.4	47	1120	.94	9.3	.94	.42	7.76	232.93	.162	2.372	.164
1995	430	62.4	49	1170	.97	9.5	.97	.47	7.76	232.93	.162	2.372	.164

LAKE HOUSTON

SUBCATCHMENT 12

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	23.7	28	550	.75	5.4	.75	.25	3.83	63.64	.064	.983	.061
1975/6 month	175	54.4	37	770	.80	7.7	.80	.30	7.45	152.37	.135	2.077	.134
1975/2 year	360	88.3	45	1120	.90	8.8	.90	.36	10.98	253.34	.207	3.211	.212
1983	390	88.6	46	1125	.90	8.9	.90	.39	11.01	330.56	.229	3.367	.232
1990	410	88.6	47	1150	.93	9.1	.95	.42	11.01	330.56	.229	3.367	.232
1995	420	88.9	49	1210	.97	9.3	.98	.46	11.05	404.61	.253	3.530	.253

LOWER SAN JACINTO RIVER

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	234	30.7	22	960	.90	4.0	.90	.00898	6	188	.101	.777	.089
1975/6 month	545	71.6	31	1492	.94	5.0	.94	.00492	14	477	.105	.971	.093
1975/2 year	1002	131.6	39	2064	1.04	6.2	1.04	.00351	21	792	.116	1.204	.103
1983	1057	138.9	39	1875	1.04	6.9	1.04	.00325	21	768	.116	1.340	.103
1990	1072	140.8	39	1908	1.09	7.3	1.09	.00321	21	782	.261	1.418	.232
1995	1104	145.0	39	2305	1.15	7.7	1.15	.0117	21	1010	.435	1.496	.387

LOWER SHIP CHANNEL

SUBCATCHMENT 1

			PEAK CONCENTRATIONS (mg/l)							TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	95	60.9	30	600	.75	6.5	.75	.25	27.35	747.81	.741	4.876	.632
1975/6 month	230	112.1	38	875	.80	9.0	.80	.40	44.57	1419.85	1.277	8.447	1.128
1975/2 year	450	168.7	44	1125	.90	12.0	.90	.50	61.79	2179.89	1.836	12.198	1.663
1983	475	170.3	48	1150	.90	13.0	.90	.50	77.92	2483.58	2.728	14.662	2.394
1990	500	171.1	56	1180	.95	13.5	.95	.55	84.18	2623.56	3.325	16.074	2.873
1995	525	172.0	60	1200	.99	13.8	.99	.60	89.61	2756.63	4.052	17.621	3.447

LOWER SHIP CHANNEL

SUBCATCHMENT 2

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD$_5$	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	433	60.9	161	9293	9.22	9.22	6.91	47.4	27	748	.741	4.876	0.632
1975/6 month	816	112.1	209	11866	13.20	41.58	9.90	71.3	45	1420	1.277	8.447	1.128
1975/2 year	1273	168.7	237	14326	15.35	48.78	11.51	88.2	62	2180	1.836	12.198	1.663
1983	1353	170.3	253	15453	24.45	60.86	18.47	99.4	78	2484	2.728	14.662	2.394
1990	1428	171.1	266	16618	39.91	75.50	28.58	108.0	84	2624	3.325	16.074	2.873
1995	1521	172.0	275	17776	64.69	94.09	44.37	117.0	90	2757	4.052	17.621	3.447

LOWER SHIP CHANNEL

SUBCATCHMENT 3

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1) BOD_5	PEAK CONCENTRATIONS (mg/1) TSS	PEAK CONCENTRATIONS (mg/1) TOTAL PHOSPHATES	PEAK CONCENTRATIONS (mg/1) KJELDAHL NITROGEN	PEAK CONCENTRATIONS (mg/1) AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS) BOD_5	TOTAL LOADS (TONS) TSS	TOTAL LOADS (TONS) TOTAL PHOSPHATES	TOTAL LOADS (TONS) KJELDAHL NITROGEN	TOTAL LOADS (TONS) AMMONIA NITROGEN
1975/1 month	541	32.0	116	9434	3.68	18.42	2.95	30.9	19	455	.630	3.179	.517
1975/6 month	1036	58.0	143	13396	4.22	24.09	3.61	43.8	30	851	1.070	5.433	.910
1975/2 year	1647	86.8	183	17636	5.64	31.60	5.08	62.2	41	1298	1.531	7.803	1.333
1983	1750	87.2	217	19128	9.53	39.82	7.85	76.6	44	1368	1.866	8.544	1.599
1990	1846	87.4	241	20613	12.87	49.62	11.71	89.7	45	1401	2.059	8.957	1.752
1995	1936	87.4	258	22179	24.96	62.12	18.86	101.0	45	1401	2.059	8.957	1.752

LOWER SHIP CHANNEL

SUBCATCHMENT 4

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	100	32.0	30	600	.75	6.5	.75	.25	18.57	455.43	.630	3.179	.517
1975/6 month	220	58.0	37	870	.80	8.9	.80	.40	29.90	851.11	1.070	5.433	.910
1975/2 year	460	86.8	43	1120	.90	11.8	.90	.45	41.26	1298.39	1.531	7.803	1.333
1983	470	87.2	47	1130	.90	12.7	.90	.50	44.21	1367.74	1.866	8.544	1.599
1990	490	87.4	55	1170	.94	13.3	.94	.60	45.55	1401.14	2.059	8.957	1.752
1995	510	87.4	59	1190	.97	13.6	.97	.62	45.55	1401.14	2.059	8.957	1.752

SIMS BAYOU

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	1829	352.3	161	3624	1.50	7.0	1.50	1.21	127	3436	.168	1.360	.148
1975/6 month	3642	701.6	176	4558	1.55	8.0	1.55	.433	231	4321	.185	1.554	.163
1975/2 year	5088	980.2	201	5663	1.65	9.2	1.65	.175	347	5368	.219	1.787	.193
1983	5194	1000.6	214	6113	1.65	9.9	1.65	.113	432	5794	.219	1.923	.193
1990	5235	1000.8	223	6386	1.69	10.3	1.69	.0964	515	6053	.232	2.001	.205
1995	5280	1017.1	220	6307	1.73	10.9	1.73	.0737	572	5978	.245	2.118	.217

SPRING CREEK

			PEAK CONCENTRATIONS (mg/1)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	260	34.1	27	832	1.21	5.7	1.21	.0887	8	174	.135	1.107	.119
1975/6 month	886	116.4	37	1234	1.26	6.7	1.26	.0645	11	518	.167	1.301	.147
1975/2 year	1881	247.0	44	1602	1.36	7.4	1.36	.0280	36	938	.231	1.437	.203
1983	1899	249.4	41	1468	1.36	8.1	1.36	.0258	36	923	.231	1.573	.203
1990	1915	251.5	39	1432	1.41	8.6	1.41	.0242	34	923	.263	1.670	.231
1995	1923	252.6	38	1405	1.47	9.4	1.47	.0235	33	920	.301	1.825	.265

TAYLOR BAYOU

SUBCATCHMENT 1

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/1)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	120	30.3	35	620	.75	6.5	.75	.30	4.55	251.81	.171	1.719	.155
1975/6 month	270	57.2	39	900	.80	9.0	.80	.35	7.56	491.28	.302	3.048	.284
1975/2 year	540	87.0	49	1210	.90	12.4	.90	.40	10.57	762.33	.438	4.441	.422
1983	575	87.7	63	1240	.95	12.9	.95	.45	15.59	918.58	.589	5.099	.555
1990	590	88.1	68	1260	.99	13.2	.99	.48	23.57	1014.26	.718	5.591	.666
1995	620	88.5	72	1280	1.05	14.1	1.05	.50	29.89	1104.06	.875	6.130	.799

WEST FORK SAN JACINTO

SUBCATCHMENT 1

			PEAK CONCENTRATIONS (mg/l)						TOTAL LOADS (TONS)				
STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN	COLIFORMS (mpn X E-5)	BOD_5	TSS	TOTAL PHOSPHATES	• KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	85	39.1	28	550	.75	5.5	.75	.25	5.87	347.59	.243	2.318	.219
1975/6 month	175	73.7	37	780	.80	7.8	.80	.30	9.73	675.77	.428	4.099	.399
1975/2 year	360	111.9	45	1100	.90	9.0	.90	.34	13.59	1047.18	.620	5.966	.593
1983	390	112.5	46	1110	.90	9.2	.90	.38	20.01	1178.46	.756	6.542	.712
1990	410	112.5	47	1120	.94	9.3	.94	.42	20.01	1178.46	.756	6.542	.712
1995	430	112.7	49	1170	.97	9.5	.97	.47	25.45	1240.84	.834	6.850	.780

WHITE OAK BAYOU

STORM	PEAK FLOW (cfs)	TOTAL RUNOFF (cu./ft. X E-6)	PEAK CONCENTRATIONS (mg/l)					COLIFORMS (mpn X E-5)	TOTAL LOADS (TONS)				
			BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN		BOD_5	TSS	TOTAL PHOSPHATES	KJELDAHL NITROGEN	AMMONIA NITROGEN
1975/1 month	3533	471.3	83	1909	1.55	7.2	1.55	.559	76	1963	.174	1.399	.153
1975/6 month	6789	905.6	110	2836	1.60	8.2	1.60	.191	140	4220	.190	1.593	.167
1975/2 year	11444	1526.6	135	3807	1.70	9.0	1.70	.0940	216	5665	.222	1.748	.195
1983	12420	1656.8	134	4048	1.70	9.5	1.70	.0911	253	6024	.222	1.845	.195
1990	13336	1779.0	136	4072	1.75	10.4	1.75	.0929	276	6060	.238	2.020	.209
1995	14202	1894.5	138	4132	1.81	11.0	1.81	.0968	298	6149	.257	2.136	.226